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FUEL SUBSYSTEMS FLIGHT TEST HANDBOOK

KENNETH J. LUSH

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FINAL REPORT

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AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE, CALIFORNIA
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This Handbook provides AFFTC engineers with guidelines for the testing of aircraft fuel subsystems. Future technological advances, characteristics of individual aircraft and test programs and cost constraints may necessitate other methods being used in some cases. A background is provided on aircraft fuel subsystems and the requirements to which they are designed. Details are provided of individual tests, test support requirements and evaluation criteria and suggestions made for presentation of results.

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PREFACE

This handbook presents the methods used in testing and evaluating aircraft fuel subsystems at the Air Force Flight Test Center (AFFTC), Edwards AFB, California. The work was done under the authority of the Study Plan for Development of a Handbook for Aircraft Fuel Subsystem Testing.

The format of this handbook is chosen to make it easily used by project engineers of the Subsystems Branch, Airframe Systems Division of Flight Test Engineering, AFFTC. It is designed to introduce a newly assigned flight test engineer to the subject and provide a working reference for planning and conduct of fuel subsystem flight tests and analysis, evaluation and reporting of results.

The material in this handbook on test planning and on analysis and interpretation was largely derived by updating, augmenting and re-formating instruction material already in existence.

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INTRODUCTION

The purpose of this Handbook is to provide the AFFTC Flight Test Engineer responsible for evaluation of an airplane fuel system with the background, philosophy and procedures for planning, conduct, data analysis and evaluation of fuel system tests. It is advisory in nature and neither supersedes Air Force Requirements nor relieves the Flight Test Engineer of the exercise of judgement in its application.

The following subjects are addressed:

1. The objective of the AFFTC evaluation and its relationship to design requirements and to the needs of the operational user.

2. Fuel system elements and basic functions.

3. A review and analysis of requirements (MIL-F-38363)

4. Planning of flight tests.

5. Data analysis and system evaluation.

OBJECTIVES AND ENVIRONMENT OF AFFTC TESTS

The AFFTC is a bridge between the design engineer and the operational user. Center evaluations of aircraft require not only engineering expertise to conduct a technical evaluation but also a keen and perceptive evaluation of the needs of the operator and of the environment in which the aircraft is to fulfill its mission. As an illustration of operation needs one may consider the tactical pilot who may have to operate in an environment ranging from difficult and distracting to actively hostile. Fuel systems should be designed to minimize pilot distraction and workload. For example, precision flying in the downwash of a large tanker is only one of many required skills and is an interruption of his basic mission. Hence, operation of the refueling subsystem should be accomplished quickly and require only a reasonable level of skill and concentration. It should also fill internal (non-droppable) tanks first. Similarly, field servicing should be fast, simple and as error proof under stress as is reasonably feasible.

Considerable attention will necessarily be given to testing against specific requirements but the flight test engineer should seek comment from flight crews with operational experience and continuously encourage ground crews to evaluate the aircraft as an operational system. The present Handbook attempts to emphasize this approach but in the last resort it cannot be fully defined in print but must be ensured by the attitude and objectives of the test team.

POSITION OF AFFTC IN THE DEVELOPMENT AND EVALUATION PROCESS

Figure 1 (page 83) presents an overview of development, test and evaluation and indicates where AFFTC fits in the process.

The contractor responds to the specific, program peculiar requirements of his contract and to general fuel system requirements with an "end item specification" for the fuel system of his aircraft. He then design his system and tests it on a simulator which embodies the actual hardware and geometry to be used. Date from these tests are primarily reviewed by the System Project Office, Aeronautical System Division. The contractor is also required to demonstrate compliance with specification by flight test of an aircraft representative of the production version.

The function of AFFTC is primarily to oversee and cooperate in these flight tests, performing independent analyses of the data and, if necessary, conducting additional tests. AFFTC also establishes actual aerial refueling envelopes, using as a starting point conservative envelopes validated by Aeronautical System Division from contractor data.

AGENCIES INVOLVED

Tests of the fuel system are usually conducted by a Combined Test Force, involving a number of Air Force agencies as well as the contractor. Table 1 (page 59) shows the interest and responsibility of each of the major agencies usually involved. It is important to appreciate the interest and expertise of the agencies involved in order to cooperate effectively. For example,

a. The contractor develops the system and demonstrates to the system Program Office that it meets specifications.

b. The System Program Office reviews and analyzes the data to check compliance.

c. The AFFTC independently analyzes data, performs additional tests as necessary, works with the System Program Office and thus provides an independent evaluation.

MULTI-PURPOSE FLIGHT TESTS

Many fuel systems tests having secondary importance will be performed during other tests or during flight which also involve other tests. Hence, the engineer responsible for the fuel system tests must:

a. See that his tests are properly performed.

b. Ensure that any incidents pertinent to the fuel system are observed and reported by flight or ground crews, whenever they occur.

Also, the engineer must work with other AFFTC organizations such as Human Factors, Reliability and Maintainability or Technical Order Verification. Such interfaces are identified in the section on planning of flight tests.

FUEL SYSTEM FUNCTIONS AND ELEMENTS

This section presents a review of the functions, subsystems and components of the fuel systems of military aircraft, illustrated by reference to actual fuel systems of a cargo aircraft (C-130H) and a modern fighter (F-15). It is the responsiblity of the project engineer to become intimately familiar with the fuel system of his aircraft and to be alert for possible weak points. Examples which have entered service include:

a. Trailing engines of a multi-engined transport starved in a sideslip.

b. All engines quit in a mild pushover.

c. Gravity fuel transfer (after transfer pump failure) insufficient to maintain level in feed tanks except at fairly nose-high attitudes.

d. Fuel going to one wing in an uncoordinated turn

e. Premature shut-off when refueling due to fuel slosh

The Air Force aircraft is a military platform whose function is to move weapons, cargo or personnel in support of military objectives. This presupposes a propulsion system, which in turn must be supported by a fuel system. Fuel is heavy and bulky and takes up a large portion of the total weight of and space available in the aircraft. Often it must be stowed at appreciable distances from the airplane center of gravity, with the result that the sequence in which the tanks are used can impact stability and controllability. Fuel is also flammable and potentially explosive. Hence the fuel system, although a support system, can have a major adverse impact on operability. The well-designed fuel system must support the aircraft in its mission safely, simply and with minimum constraints. It must operate satisfactorily throughout the flight envelope and during all permissible maneuvers on aircraft "normally operated by a single pilot" it must be fully automatic in its normal flight functioning after activation.

Fuel system functions and elements will now be discussed with particular relationship to:

a. The C-130H system, representative of system supervised by a flight engineer.

b. The F-15A system, representative of an automatic system for an aircraft "normally operated by a single pilot".

The schematic for the C-130H system is shown in Figures 2 (port side) and 3 (starboard side). The fuel control panel, which is mounted overhead, is shown in Figure 4 (page 86). This panel shows a quite effective approach to meeting the requirements of MIL-F-38363B, paragraph 3.5.3.10, for cockpit fuel controls, which include the following:

Controls shall be grouped in a functional manner.

A simplified diagram shall be inscribed on the panel with tanks represented by their symbols or by quantity indicators.

Switches shall clearly indicate ability of fuel to flow or be stopped.

Figure 5 (page 87) shows the tank layout and the gaging presentation for the F-15A. The gage pointer indicates total internal fuel (with readings multiplied by 1000). The upper counter marked TOTAL LBS indicates total internal plus external fuel. The two lower counters, marked LEFT and RIGHT, and a selector switch provide individual tank monitoring and a check of the indicator. Figure 6 shows the location of the fuel system controls and indicators. Since the F-15A system is basically automatic, the panel is rather simple. The schematic for the total system is shown in Figure 7.

TYPICAL FEATURES OF FUEL SYSTEMS

The C-130H fuel system is reasonably representative of multi-engined aircraft. Also, as it is manually controlled by the flight engineer the implementation of some functions is more easily followed. This system (Figures 2 through 4) will therefore be used to illustrate the basic functions and features of the fuel systems of military aircraft.

It is required that there be one main (feed) tank per engine, by which that engine is normally supplied (tanks 1 through 4 of Figures 2 and 3). Fuel is normally pumped from each main tank by a booster pump. Unless the primary feed is by gravity flow there must be a backup mode such as tank pressurization or gravity feed. (The C-130H uses gravity feed as backup.) There is a low pressure warning light switch at each engine.

It is also required that it be possible to feed any or all engines from any main tank. Control of this "cross-feed" is effected by the cross-feed valve switches and cross-feed separation switch (between port and starboard sides, primarily to balance fuel in the two wings).

Other tanks, whether internal or external, are classified in MIL-F-38363 as "transfer" tanks. Usually these replenish the main tanks. In the case of the C-130H, however, they feed the engines directly through the cross-feed manifold. Their pumps deliver a higher pressure than those in the main tanks, resulting in preferential feed from the auxiliary tanks. The C-130H has two internal auxiliary tanks and two optional external tanks.

Military aircraft are now required to have an explosion suppression subsystem such as nitrogen (or Halon 1301) pressurization or reticulated polyurethane foam. The C-130H does not have this, while the F-15 has foam for fire/explosion suppression.

Tanks must be protected from excessive differential pressure, positive or negative. The C-130H tanks are vented to the atmosphere. Those in the F-15 are pressurized by engine bleed air, which maintains positive pressures during fast descents, and have excess pressure venting. Tanks must be designed to leave an expansion space when filled normally, but overboard venting of excess fuel must also be provided.

MIL-F-38363 requires that all aircraft with an internal fuel capacity of 600 gallons or more should have provision for refueling of all tanks from one or more pressure refueling points. The C-130 has a single point located in the right aft landing gear fairing. This receptacle can be used for refueling and defueling. It supplies the tanks through the refueling manifold, each tank having its own float operated shut-off valve. Each tank can also be individually filled through a filler opening in top.

Provision should be made to dump fuel quickly and safely in preparation for an emergency landing. On the C-130H there is a dump switch for each tank. The system dumps all fuel overboard except 2100 pounds in each outboard main tank, 1800 pounds in each inboard main tank and 60 pounds in each external tank.

A sump is usually provided in each tank to collect water and contaminants. This must be drainable without draining the tank. The C-130H has a system to keep the water stirred up. It also has a heater at each engine to prevent ice in the fuel from blocking the fuel flow.

Aerial refueling is provided in most Air Force aircraft. This is discussed below as part of the discussion of the subsystem.

FUEL SYSTEM SUBSYSTEMS

MIL-F-38363 divides the fuel system into eight subsystems. The functions of these will now be discussed, using the C-130H and F-15A/B as illustrative examples.

Engine Feed and Transfer Subsystem:

This moves the fuel from the tanks to the engine(s) and also moves fuel between tanks. Each engine is normally supplied from its own "main" or "feed" tank but on multi-engined aircraft it is required that any or all engines can be supplied from any main tank. In normal operation fuel is transferred out of the main tank by a fuel boost pump, with engine compressor bleed pressurization or, in some cases, gravity feed as a backup.

Boost and transfer pumps are commonly operated individually by electrical or hydraulic power. The A-7 and the A-10, however, use ejector pumps for boost and transfer, operated by high speed fuel flow from other pumps. On the A-7, for example, there are two such primary pumps, one engine driven and one hydraulically driven. Ejector pumps are very simple and highly reliable.

In the case of the C-130H the boost pump switches for the main tanks, the cross-feed valves, and the transfer controls to move fuel from the auxiliary and the (optional) external tanks are all mounted on the fuel control panel (Figure 4 Page 86). All control is manual. In contrast, the F-15 feed and transfer subsystem is automatic. The control panel is limited to (a) switches to control transfer from and refueling of the external tanks, (b) a refueling slipway control switch and (c) a dump switch. Fuel is transferred from the external tanks to internal transfer tanks by regulated bleed air pressure only. The bleed air pressure to the wing external tanks is higher than that to the centerline tanks, so that they normally transfer first. Transfer from the internal transfer tanks to the feed tanks is normally by pumps which run continuously. Fuel can be gravity fed if the transfer pumps should fail. Feed to the engines is normally by right and left main boost pumps. These are backed up by an emergency boost pump in the left engine feed tank (actually, a pair of interconnected tanks) which can feed both engines and is automatically activated in the case of a failure of either boost pump. The emergency pump alone can supply both engines at all non-afterburner settings at altitudes up to 30,000 feet. Cross feed in emergency operation is automatic.

Fuel Tank Subsystem:

As noted above, there must be one "main" or "feed" tank per engine. All other tanks are classified as "transfer" tanks, including fixed tanks and droppable tanks. In some systems transfer tanks can supply the engine directly by an override system.

The C-130H has four integral main tanks (one per engine) and two auxiliary tanks in the wing inboard of the engines. Each auxiliary tank is made up of three bladder type cells interconnected to form one assembly. Additionally, two optional all-metal external fuel tanks may be carried on pylons between the inboard and outboad engines. The F-15 has four internal fuselage tanks and two integral (wet) tanks in the wings. External fuel may be carried in thre droppable tanks mounted on the centerline and at the inboard wing stations or, in later models, in "conformal" tanks. Fuselage tank 2 normally feeds the right engine and tanks 3A and 3B, which are interconnected, the left engine. All other tanks are transfer tanks.

Pressurization and Explosion Suppression Subsystem:

Regulated bleed air is used to maintain a positive pressure in all tanks. It is also used to transfer fuel from external tanks to internal tanks and may also be used as a backup means of internal transfer. An explosion suppression subsystem is now called for, normally either baffle material (reticulated polyurethane foam) or an inert gas system. The F-15A has foam protection. The C-130H does not have an explosion suppression system or bleed are pressurization.

Fuel Vent Subsystem:

Vents are required to protect the fuel tanks from destructive pressures during, for example, fast descent. They must dump any excess fuel safely, but must not permit siphoning or cause transfer of fuel between tanks trough the vent plumbing. The C-130H tanks are vented to maintain atmospheric pressure. The inboard main tanks and the auxiliary tanks have a "wraparound" vent system which permits venting even when the wings are not level. The outboard main tanks are vented by a float controlled vent valve to prevent loss of fuel overboard on the ground. In contrast, the F-15A tanks are pressurized as soon as the weight is off the landing gear and are protected by excess pressure relief valves and also vacuum relief valves.

Fuel Quantity Gaging Subsystem:

It is required that this give a continuous reading of total fuel and of the fuel in each main (feed) tank. Quantitites in other tanks may be shown by switching. If the center of gravity of the fuel is important (and controllable by the crew) this also must be displayed. Figures 4 and 6 (Pages 86 and 88) show the gaging presentation for the C-130H and the F-15A, respectively. It will be seen that each is well suited to the needs and environments of the operational crews.

Ground Refueling and Defueling Subsystem:

On all aircraft with an internal fuel capacity of 600 gallons or more provision must be made for pressure refueling of all tanks from one or more points as desired, as well as for gravity refueling. Provision must be made for defueling normally and after a wheels-up landing. The C-130 is pressure refueled or defueled on the ground from a single-point receptacle in the right aft landing gear fairing. The F-15A is pressure refueled at a point below the fuselage and defueled at a point by the right main wheel well. It does not meet the requirement for defueling after a wheels up landing without being raised to provide access to the defueling point.

<u>Aerial Refueling Subsystem</u>:

Paragraph 3.12 of MIL-F-38363B states that "all aircraft shall have aerial refueling capability installed or the space and structural provisions for aerial refueling". This subsystem is a major concern of AFFTC flight test since it involves inflight performance and handling compatibility of tanker and receiver, operating envelopes and the overall acceptability of the tanker-receiver combination in the appropriate operational context. Provision is required to refill all/any tanks in flight. Large aircraft use the boom/receptacle technique but aircraft with gross weight below 75,000 pounds may use the probe and drogue method if this is shown to be more suitable.

The boom method requires that the receiver aircraft fly accurate formation behind the tanker and in its down wash, the angle of which varies with both vertical and horizontal location, while the receiver weight is changed markedly by loading fuel. Position is attained using director lights on the tanker and boom operator instructions if radio transmission is permissible. The boom operator then inserts the (telescopic) boom in the receiver receptacle. The boom is normally locked in place, extractable in emergency by a tension disconnect, but in case of failure of the catch, contact can be maintained by boom pressure. After connection has been made communication is by an induction system in the boom.

Figure 8 (page 90) illustrates the boom installation of the KC-135 tanker. The operator can control the boom in length, azimuth and elevation. It must be recognized that in KC-135 boom operation "elevation" is measured <u>downward</u> from the tanker waterline. The boom is controllable in length from 404 to 551 inches (6 ft to 18 ft extension). The mechanical limits in azimuth are ± 30 deg, but disconnect is effected at ± 10°. The disconnect envelope in "elevation" is 20 deg to 40 deg (downward from the tanker waterline).

The KC-10 has an Advanced Aerial Refueling Boom which gives a wider azimuth envelope and greater maximum length. It is controlled in "pitch" and "roll", where "pitch" is the angle between the boom and an approximately horizontal reference axis and "roll" involves describing and arc about that axis (Figure 9). (This is rather similar to aircraft pitch and roll measured relative to the direction of flight). The pitch envelope is 20 deg to 60 deg and the roll envelope ± 25 deg. Its length is 434 inches retracted and 680 inches extended, but in operation the telescopic extension is form 5 feet to 22 feet.

The receiver has a receptacle feeding the refueling manifold, a slipway to guide the boom nozzle into the receptacle and, usually, a retractable door. The slipway has lights to illuminate both it and the receptacle bore for night refueling. The receiver pilot also has indicator lights as follows:

	Blue	"Ready" for contact
	Green	"Latched"
	Amber	"Disconnected"
and optionally	Green	"Door unlocked"

Probe drogue tanker installations are of two types. The KC-135 uses a boom to drogue adapter kit with which a boom operator has some control over the drogue position, which can be used in testing to establish a disconnect envelope (Figure 10 page 92). Other installations such as that in the KC-130 and the hose/reel system in the KC-10 do not have this kind of control by the tanker. In all cases the receiver pilot is responsible for hook-up by maneuvering the probe on his aircraft into the drogue receptacle.

Fuel Dump Subsystem:

This is required to enable fast, safe off-loading of fuel while in flight in preparation for an emergency landing or an impending crash condition. The C-130H has a fuel dump switch for each tank. With the F-15A dumping is initiated by a single switch. A dump valve is opened in each internal wing tank, upon which the transfer pumps in fuselage tank No.1 and the internal wing tanks force fuel out of the wing dump mast(s). The external fuel transfers into the wing tanks and tank No.1 and is then dumped. Fuel from the main (feed) tanks is not dumped.

Heat Exchangers:

On high performance aircraft fuel is used as a convenient heat sink into which to dump excess heat from oil, avionics systems and so on. For example, on the F-15 (Figure 7) fuel pumped from the main tanks passes through heat exchangers on its way to the engines. If the fuel temperature out of these heat exchangers exceeds 195 deg. F bypass valves open which allow additional fuel flow to the exchangers. This additional fuel flow, which is limited to 10 gal/min per engine is returned to the internal wing tanks and so cycles back through the system. This type of arrangement can result in excessive engine fuol inlet temperatures in flight after hot soak on the ground. It can also result in the cooled systems going off line if boost pumps fail, due to heat build up in the cooled systems. Particular attention should be paid to fuel temperatures at the engine fuel pump inlet in high Mach number aircraft at conditions when aerodynamics heating may cause high temperatures in the fuel in the tanks.

REVIEW OF DESIGN AND TEST REQUIREMENTS

This section reviews the requirements for design and test of fuel systems from the standpoint of the AFFTC flight test engineer, who represents the ultimate user of the aircraft, in order to familiarize the engineer with the total test picture and with the background against which he is to plan and conduct his tests. Detailed discussion of planning and conduct of specific tests on specific aircraft follow in a later section.

General requirements for the design and test of fuel systems are contained in Military Specification MIL-F-38363. Based on this, the supplier:

a. Creates a fuel system specification for the proposed airplane which forms part of the "end item specification" of the contract. This, including any variances from the general specification, must be approved by the procuring agency.

b. Performs tests on a simulator to verify fuel system performance. The simulator reproduces the geometry and hardware to be used on the airplane.

c. Performs ground and flight test on an airplane representative of the production version to finally demonstrate fuel system performance.

The function of AFFTC is primarily to oversee and cooperate in (c), perform independent analysis of the data and, if necessary, perform additional tests to ensure that the airplane meets requirements, with special emphasis on being satisfactory in the operational environments in which it will be used.

Design requirements are given in Section 3 of MIL-F-38363[1] for the fuel system as a whole and for each subsystem. Tests to be performed on the simulator are specified in Section 4.4 and tests to be performed on the airplane in Section 4.5 Of the requirements in Section 3, some are detail design requirements, verifiable against the detailed fuel system specification for the particular aircraft, while others require verification by test on the simulator and/or the aircraft.

[1] Specific paragraph references in the following discussion are to MIL-F-38363B. The reader should consult the most recent revision of the specification.

CLASSIFICATION OF REQUIREMENTS OTHER THAN FLIGHT REFUELING REQUIREMENTS

In developing an overview of the program, it is helpful to first consider all requirements not associated with aerial refueling as a group. It is also helpful to subdivide this group as follows:

a. Requirements associated with normal fuel system functioning under all design operating conditions.

b. Requirements for operation with one or more component failure.

c. Requirements associated with specific items, conditions and functions (e.g., fuel dumping).

d. Maintainability and serviceability requirements.

Nominal Fuel System Functioning[2]:

Requirements of this type which lead to flight test requirements are summarized in Table 2 (page 60). In essence these requirements are that in normal operation, without component failure, all aspects of fuel system operation shall function correctly under all design operating conditions. Examples are continuous feed to the engines under all conditions, control of center of gravity, tank pressurization and venting. The flight test requirement is to confirm proper functioning over the flight envelope. Hence one key to effective and efficient flight test is to identify those parts of the operational envelope which stress the functions to be verified. As an obvious example, fast, high-powered climb stresses tank venting, fuel feed and transfer while fast descent checks pressurization. Fast rolls, sideslip, pushovers and (where applicable) inverted flight check fuel feed in necessary parts of the flight envelope. Multiengined aircraft have in the past entered service whose engines flamed out in sideslip or in a mild pushover (0.3g). Severe weight asymmetry has resulted from unintended fuel transfer between wings in uncoordinated turns.

Operation with One or More Component Failures:

Requirements of this type which lead to flight test requirements are summarized in Table 3, page 63. It is required that the aircraft be able, for example, to complete its mission in the event of failure of one booster pump or one transfer pump. Hence, operation of all engine at MAX power must be possible in the event of such failure on aircraft with afterburning engines.

2 "Nominal" functioning is without subsystem or component failure.

Requirements Associated with Specific Conditions and Functions:

This is a mixed group (Table 4 page 64). Requirement 3.5.3.2.1, that "the fuel system shall be designed to operate throughout the temperature range shown in Table 5" requires repeating a selected set of the general functional tests in extreme temperature environments (Alaska, Eglin Climatic Hanger). Demonstration of compliance with 3.5.3.2.2 (ice in fuel) could be part of the above tests or could be an independent ground test.

Compliance with the requirement for safe, fast fuel dumping and the requirements on fuel transfer (Section 3.6) will obviously be demonstrated by specific direct flight tests.

Maintenance and Serviceability Requirements:

When testing for compliance with maintenance and serviceability requirements it is particularly important to evaluate compliance in the expected context of operational maintenance. High priority flight test programs may have a degree of specialized contractor assistance which would not be available to an operational unit. The flight test engineer should ensure that the operational context is kept in mind by all personnel concerned with evaluation of maintainability and serviceability.

Table 6 page 67 summarizes major requirements in the category from MIL-F-35363. There is a blanket requirement for maintainability with standard tools (paragraph 3.4) which should be kept in mind by all concerned throughout the test program. There are a number of specific requirements on accessibility for which suggested approaches are given in the comments column. In general, if the Maintenance Manual procedures meet requirements a check test should only be necessary if there is reason to doubt that these procedures are realistic. However, the times to install tanks (paragraphs 3.7.1.9.1 and 3.7.2.2.2) should be checked for representative cases for the operational style maintenance context. Refueling times must be checked by specific dedicated tests. Items such as liquid nitrogen servicing rates can conveniently be checked during routine maintenance.

REQUIREMENT ASSOCIATED WITH FLIGHT REFUELING

This Handbook addresses only testing a receiver aircraft in association with fully qualified tanker, since the need to qualify tankers arises infrequently.

The emphasis of tests associated with aerial refueling is somewhat different from that of other tests of fuel subsystems. In the other tests, the emphasis is on showing that the fuel system, in addition to meeting a number of specific requirements, does not unduly constrain the operational capability of the aircraft. In aerial refueling tests, the configurations and performance envelopes of the tanker aircraft are given and the emphasis of the flight tests is quite largely on establishing a refueling operational envelope over which refueling can be satisfactorily performed in the expected operational environment. As a result of this difference, Section 4.5 of MIL-F-38363B calls for a substantial amount of testing which is aimed at establishing this receiver/tanker interface rather than at demonstrating compliance with specific requirements laid down in Section 3.12 of the specification. AFFTCR 80-3 establishes general requirements for aerial refueling testing. Instrumented KC-135 and KC-10 tankers are used.

Test aircraft which have unqualified aerial refueling systems must have an approved preliminary aerial refueling envelope established before any aerial refueling tests. Approval is normally the responsibility of the system program office for the receiver aircraft being tested. The system program office should furnish the approved preliminary envelope to Bomber Test Operations and Flight Test Engineering, Subsystem Branch for review before scheduling refueling tests.

The ground tests are summarized in Table 7 (page 72) for both receptacle and probe/drogue systems. These are designed to check functioning as far as possible and establish a conservative operational envelope before proceeding to flight tests. Functional tests are performed of all components.

If feasible, the effectiveness, placement, brightness/dimness and aiming of receptacle and formation lights, pilot director lights, boom nozzle lights, drogue lighting and platform reference lights will be evaluated on the ground under simulated night conditions. Receiver lighting will be evaluated by boom operators for boom receiver qualifications. Receiver pilots will evaluate drogue lighting for probe receiver qualification. Both the boom operator and receiver pilot will evaluate the adequacy of night lighting for tanker qualifications.

Also, if feasible, tanker/receiver compatibility will be checked at the boom 0 degrees azimuth position and a limited number of fuel transfer rates on the ground prior to aerial refueling.

To fully qualify receiver aircraft, the following flight testing will be performed:

(1) Accomplish all items to qualify a receiver or tanker aircraft: system compatibility checkout, proximity tests, approved aerial refueling envelope.

(2) Demonstrate functional compatibility for tanker and receiver manual operation.

(3) Demonstrate pressure refueling.

(4) Perform pressure disconnects in accordance with MIL-F-38363 and AFFTCR 80-3.

(5) Demonstrate tension disconnects to establish system integrity at several boom angular positions in accordance with MIL-F-38363 and AFFTCR 80-3.

(6) Demonstrate use of independent disconnect capability (if applicable).

(7) Demonstrate reverse refueling (if applicable).

(8) Demonstrate the adequacy of night refueling.

Flight testing proceeds in the following sequence:

a. Proximity tests are performed to establish envelope compatibility for airspeed, altitude, formatting capability, aircraft configurations and gross weights.

b. Contacts are accomplished initially within a conservative contact envelope. This contact envelope is then expanded in an orderly and conservative manner in conjunction with disconnect envelope expansion.

c. Disconnect envelope expansion is conducted by selection of coordinate points for an orderly and conservative envelope development. Envelope limits are determined through this process.

Probe/drogue aerial refueling qualification testing will similarly include ground and flight tests and will proceed in a manner analogous to the boom method of refueling. The boom to drogue adapter kit (BDA) will be installed on the instrumented NKC-135A or an instrumented hose-reel installation (KC-10) will be used for receiver or tanker aerial refueling qualification.

ALL-WEATHER TESTS AND TESTS WITH ALTERNATE FUELS

All aircraft are required to undergo All-Weather testing. Tests with alternate fuels are required to ensure interoperability for aircraft to be deployed to Europe (NATO forces, JP8) or the Pacific (US Navy, JP5). Handbook deals only with the fuel subsystem parts of such tests and does not consider, for example, engine starts at very low temperatures or with alternate fuels.

All Weather Testing:

Procedures for these tests are described in Reference 3. These programs normally include tests in the McKinley Climatic Laboratory at Eglin AFB and field test at sites such as Alaska (winter), El Centro NAS (desert summer) and in the Canal Zone (tropical).

Essentially full operational capability is required under extreme operational conditions, although some special procedures may be acceptable for an otherwise satisfactory system. The full range of fuel subsystem tests is not repeated, but normal operational profiles are demonstrated. For high performance aircraft with oil-fuel heat-exchangers the program should include high speed low altitude flight after ground heat soak to evaluate fuel control inlet temperatures. Tests will also include, in addition to normal operational profiles:

1. Ground and flight tests with failed boost pumps.

2. Checks of adequate fuel expansion space and venting and fuel drain.

3. Checks of functioning of refueling doors, etc., after icing or under freezing conditions after rain.

4. Checks of tank sealing under extreme temperatures.

5. Tests with alternate fuels.

6. Tests of any components suspected to be susceptible to extreme weather condition.

The required fuel subsystem tests are defined in a Test Information Sheet, which is integrated into a Test Integration Plan by the All-Weather test engineer (Reference 3).

Alternate Fuel Tests:

Essentially full operational capability is required with an alternate fuel. Usually however some special procedures under adverse (e.g. very cold) conditions are necessary and are acceptable. Testing will, however, address only components and operations which could be affected by the change in fuel. Primary concern is usually with use of kerosene type fuels for turbine engines (JP5, JP8 or commercial jet fuels) as alternates to JP4 (gasoline).

Military JP-4 and commercial Jet B are gasoline type fuels the others are kerosene type fuels. The purpose for JP-4 is to meet military operational requirements - specifically low temperature/high altitude.

The Navy (JP-5 fuel) sacrificied military operational requirements (low temp - high altitude) to minimize fire hazard on board aircraft carriers. The commercial airlines are concerned with cost and fire hazard, thus Jet A and Jet A-1 are similiar to JP-5 but because of cost the flash points are not as high as JP-5. The commercial Jet B is the commercial equivalent of JP-4. Although the specification shows only minus 50 deg F freeze point, it is a gasolene type fuel and as such has a much lower freeze point than the kerosene type commercial fuels Jet A and Jet A-1. As in the case of JP-4 it has a very low flash point because of the increased fire hazard and the higher cost, Jet B is not used as much as Jet A and Jet A-1 fuels.

Table 8 (Page 73) presents a comparison of significant parameters taken from References 4 and 5. Those of primary significance are viscosity (primarily at very low temperatures), density and dielectric constant, flash point and the presence of icing inhibitors. Kerosene fuels may have quite high viscosities at low temperatures (e.g. -30 deg F) and freeze at around -60 deg F This can affect engine feed and intertank transfer flows at low temperatures. It can also affect the engine fuel controls, which are not legally part of the fuel subsystem but would be evaluated during the same test program. Density and dielectric constant can affect fuel quantity indicators. The higher flash point makes kerosene fuels safer to handle but can affect engine starts at low temperature. (When C-5s were being used to ferry equipment to Israel they had to keep enough JP4 to start the engines. They could then operate with the commercial type fuel available). Thus the primary thrust of fuel subsystem tests with alternate fuels will be to evaluate fuel feed and transfer, including spot checks of degraded configurations likely to be affected (e.g. gravity feed), and quantity indication. JP5 and JP8 both have icing inhibitors added, so fuel icing should not present a special problem. Appendix C (Page 119) gives an example of the kind of operating limitation which may be required with alternate fuels.

PLANNING OF FLIGHT TESTS

This Section addresses planning of the content of the fuel system flight test program. The administrative procedures required to execute these plans are common to all AFFTC flight tests and will change from time to time. The engineer should familiarize himself with AFFTC Regulation 80-12 (Test Plan) and AFFTC Regulation 80-13 (Test Plan Technical Review) and related documents. An example of a Test Information Sheet (TIS) for a fuel system evaluation is given in the Appendix A (Page 93).

Safety planning procedures are similarly applicable across the board to flight testing and the engineer should familiarize himself with references 8 and 9. Certain aspects of fuel system testing are, however, particularly hazardous and call for very careful attention to safety by the engineer. Examples are refueling (especially "over-wing"), hot refueling, defueling, and tests with boost pumps off. Examples of Test Project Safety Reviews (AFFTC Form 28) are given in Appendix B (Page 105).

Fuel system tests will usually be conducted in the context of Combined Test Force (CTF) operations and will consist of a coordinated, combined program. This program should be designed to meet the needs of all interested parties - primarily the contractor, Systems Program Office (SPO) and AFFTC. Since a primary requirement is that the contractor demonstrate compliance with specifications to the satisfaction of the SPO, the contractor will normally take a leading role in planning and executing the tests. The AFFTC flight test engineer must, however, ensure that the test program and the data acquired are adequate to meet AFFTC responsibilities and must independently analyze the data and evaluate the fuel system. This engineer should also establish good communications with flight and ground crews and ensure alertness to all fuel system incidents relevant to evaluation.

The flight test engineer must become thoroughly familiar with the system both as described in Flight and Maintenance Manuals and as it exists in hardware form. These versions may differ significantly in the development phase of a new aircraft (and sometimes in later phases).

Careful record keeping is important. The engineer should make and adhere to specific plans to maintain detailed, accessible and complete test records for his own protection and for the benefit of his successor in case of promotion, transfer or unscheduled demise.

Information sources to be reviewed, and referenced in Test Information Sheets and reports, include the following:

- Test Aircraft Flight Manual, ("dash 1") and/or Crew Checklists
- Aircraft Contract End Item Specifications
- Military Specifications pertaining to the individual system or test
- Organization Maintenance Manuals ("dash 2")
- Field Maintenance Manuals
- Contractor System Operation and Service Manuals
- Related AFFTC Reports
- Formally published Contractor Test Plans
- Formally published Contractor Test Reports
- Program office requests (letters, TWX's, etc.)
- Related test plans includes those of other participating commands
- Test Plan Safety Reviews (AFFTC Form 28) for similar test programs

Detailed discussions of specific tests are grouped below as follows:

a. ground tests
b. flight tests other than aerial refueling
c. aerial refueling flight tests
d. all weather testing
e. alternate fuel operation

These discussions are designed to provide readily accessible reference material to the flight test engineer. It is recommended that at first reading they be skimmed over fairly lightly.

FUEL SYSTEM GROUND TESTS

Fuel system ground tests will include the following:

1. Fuel quantity system calibration and center of gravity measurements.

2. Ground refueling and defueling.

3. Verification of various maintenance and accessibility capabilities.

Additionally, the following ground tests are performed prior to the corresponding flight tests:

4. Ground evaluation of fuel transfer.

5. Ground evaluation of operation with failed boost pumps.

6. Ground evaluation of aerial refueling system.

Recommended data parameters to be recorded on these tests are summarized in Table 9A (Page 74).

Quantity System Calibration:

Test Objectives. These are:

1. To determine usable fuel quantity.

2. To correlate usable fuel in the aircraft with indicated fuel quantity.

3. If center of gravity indication is provided, to correlate actual with indicated center of gravity.

4. Specific objectives requested by the Program Office.

Test Conditions/Procedures. The fuel quantity system calibration test will be conducted at the AFFTC Weight and Balance (W&B) facility (AFFTCR 80-5). This facility allows the test to be conducted under relatively constant temperature, no-wind conditions. The airplane can be jacked in the W&B facility to simulate level or nose up/down attitudes. The specific gravity and temperature of the fuel added or removed from the airplane during the course of the evaluation can be determined and the amount measured by a flowmeter. An equivalent contractor facility may be acceptable provided that adequate oversight of the tests is provided.

The tests must include a check for sensitivity of fuel quantity (and center of gravity) to attitude. The number of attitudes to be checked depends on the tank configuration. As a minimum, calibrations should be performed at ground attitude and at the maximum flight deck angle. (Care must be taken not to tip the aircraft on to its tail). If the tanks are long in the fore and aft direction and shallow then as many as four attitudes may be required.

Prior to the fuel quantity system calibration all quantity system indicated should be calibrated in accordance with Technical Order maintenance procedures. The airplane should be fueled to its completely full configuration using the normal preflight fueling method. Normally, external fuel tanks are not included in this evaluation. The airplane will then be towed onto the W&B scales, leveled and weighed with all power leads and refueling hoses installed and a crew member or test engineer onboard to operate the fuel system controls and read the quantity indicators. The leveling will be performed according to the procedures in the Organizational Maintenance Manual for Ground Handling and Servicing. Generally, longitudinal level is obtained by raising or lowering the scale under the nose landing gear or tail wheel. Lateral level must be obtained by inflating or deflating the main gear struts or by using plywood shims. The aircraft will then be defueled incrementally, one tank on cell at a time, and leveled and weighed after each increment. At least two increments will be made per tank, more if the tank is of irregular shape. At the same time as the aircraft is being weighed, the on-board crewman will hand record all fuel quantity indications and a ground crewman will hand record the aircraft weight, number of gallons offloaded, and the temperature and specific gravity of the fuel. The order of defueling the tanks will be approximately the same as that for normal inflight burnoff and will continue until all tanks have been reduced to "unpumpable" or "unusable" fuel. This will also produce the base-line weight of the aircraft. The aircraft will then be refueled incrementally to its completely full configuration. The procedure will be approximately the same as for the defueling portion of the test except that the sequence of tanks will be reversed, i.e., the last tank emptied will be the first one filled, etc. The same hand-recorded data will be taken.

If possible, this test will be conducted concurrently with the weight and balance postion of the Performance and Flying Qualities evaluation which will also determine aircraft center of gravity as a function of fuel quantity onboard. Test instrumentation must be calibrated at the same time.

Data/Support Requirements. The following support is required to satisfy the test objectives of the fuel quantity system calibration test:

1. Weight and balance facility and associated equipment.

2. Indicator calibrations, in accordance with maintenance.

3. Fuel truck support and specialized refuel/defuel adapters.

4. Fire truck

5. Necessary data parameters are as follows:

5.1 Individual tank fuel quantity - all tanks
5.2 Fuel quantity totalizer indication
5.3 Fuel temperature
5.4 Fuel specific gravity
5.5 Actual aircraft weight
5.6 Test instrumentation parameters (Table 9A, (Page 74).

The engineer should, when planning the tests, setup data recording sheets appropriate to the specific aircraft, to ensure that all necessary parameters are recorded.

Ground Refueling/Defueling Evaluation:

Test Objectives. These are:

1. To determine maximum ground refueling and defueling rates.

2. To evaluate ground refueling/defueling procedures and checklists.

3. Specific objectives requested by the Program Office.

Test Conditions/Procedures. The ground refueling/defueling evaluation will be conducted in the normal aircraft parking area or at a ground refueling pit. Environmental conditions will be as close to ideal as practical, i.e., fair weather, no wind, standard day or tropical day temperature, etc. The refueling/defueling tests will be conducted using the overall procedures of the Organizational Maintenance manual. Tests will always include configurations with external tanks, when applicable.

Refueling with JP4, which is a gasoline, is inherently very hazardous. "Overwing" refueling is the most hazardous, but even single point refueling forces explosive vapor out of the vents. It is essential not only that prescribed safety procedures be strictly followed but that no static producing clothing (nylon, rayon, wool, plastic) be worn in the vicinity of the operations. People have been killed that way.

Overwing Refueling "Overwing" (gravity) refueling, which includes gravity refueling of fuselage as well as wing tanks, will be conducted where applicable using a standard fuel truck and hose/fuel nozzle to fill the aircraft fuel tanks through the fuel service ports on the top of each wing. The refueling sequence will be evaluated for average refueling rate, practicality and problem areas such as poor access, fuel foaming out of the service port which requires a reduced rate, and safety. It will not be necessary to completely fill the aircraft to complete this test; however, one tank should be filled to evaluate the ability to fill the tank.

Single Point Refueling Single point refueling (SPR) will be conducted using either a standard fuel truck and hose with a SPR adapter, or a ground refueling pit and a SPR adapter. These will be connected to a SPR connector on the aircraft to refuel it through its own internal fuel manifold. The number of receiving tanks will be varied and both manual and automatic features utilized. The refueling sequence will be evaluated and compared to the overwing method. Areas included in the comparison include refueling rate, practicality, and ease of refueling. Problem areas such as poor access, leakage, high or potentially dangerous manifold pressure and other safety items will be identified.

Hot Refuel and Quick Turnaround For tactical aircraft tests of refueling with engines running are now frequently required. These require special care, including consideration of the configuration of the particular aircraft. Consideration should be given to the locations of filling points and airflow vents relative to possible hot points such as brakes. Appendix B (Page 105) has examples of a Test Plan Safety Review for this test, for the F-16. The engineer should study this and similar safety reviews carefully. It is also good practice to review hot refueling procedures in Flight Manuals for similar classes of aircraft. An example is included in Appendix C (Page 119)

Defueling The routine defueling method for individual fuel tanks presented in the Organizational Maintenance Manual will be evaluated for ease, practicality, defueling rate and safety/problem areas such as access, fuel spillage potential, etc. It will not be necessary to completely defuel the airplane to complete this test.

Single Point Defueling Single point defueling will be evaluated using a fuel truck or a ground refueling pit as described in the single point refueling test. The number of tanks and pumps will be varied. This refueling method will be evaluated for ease, practicality, defueling rate and safety/problem areas such as poor access, leakage, high or dangerous manifold pressure and other safety items. It will not be necessary to completely defuel the aircraft to complete this test.

Data/Support Requirements. The following support is required to satisfy the test objectives of the ground refueling/ defueling evaluation:

1. Fuel truck/refueling pit support and specialized refuel/defuel adapters.

2. Fire truck

3. Still photography (color plus black and white).

4. Motion picture photography (24/48/250 fps color, 16mm).

5. Fuel system parameter instrumentation package (in aircraft).

6. Reduction of recorded data.

Necessary data parameters are summarized in Table 9A (Page 74)

Accessibility and Maintainability Requirements:

This area of testing involves the Human Factors and the Reliability and Maintainability branches within Flight Test Engineering and the Technical Order Verification Management Division of Maintenance and Supply. Usually the fuel subsystem flight test engineer will not take the lead role in planning these tests, but he should make himself aware of what is being done and use good judgment as to how actively he involves himself in this area.

Test Objectives These are:

1. To verify operational suitability.

2. To verify compliance with the general requirements of MIL-F-38363.

3. To verify compliance with the appropriate end item specification.

4. Specific objectives requested by the Program Office.

Test Conditions and Procedures. Maintenance and serviceability requirements, which include accessibility requirements, are summarized in Table 6 (Page 67) These are of three general types:

a. Those which can be verified by inspection of the fuel system feature (e.g., 3.6.6.1, 3.11.1.6 MIL-F-38363B)

b. Those which can be verified during routine maintenance (e.g., 3.7.1.3.2, 3.8.2.2.5)

c. Those which may require programming specific tests, depending on maintenance history during the test program (e.g., 3.7, 3.7.1.4, 3.7.1.9.1)

The engineer should make up a test matrix/checklist, based on the test objectives and the appropriate specifications. Table 10 shows a possible format, which should not be slavishly followed. Requirements of type (a) will be worked off by the engineer in consultation with the maintenance crew and the representatives of the user Commands. Requirements of type (b) will be addressed similarly as opportunity arises during routine maintenance. Specific tests will be called for tc respond to requirements of type (c), but these tests will be combined with necessary maintenance operations should the opportunity arise.

Data Requirements. A record should be kept as the requirement of the matrix are checked. When the airplane fails to meet requirements the nature of the problem and the degree of non-compliance must be recorded, together with any recommendations for corrective action.

Ground Fuel Transfer Evaluation:

Test objectives These are:

1. To evaluate the normal fuel management system (if this system is automatic it will sometimes be necessary to perform this evaluation along with the tests of feed with boost pumps failed so as to achieve representative flows and tank sequencing).

2. To evaluate the procedures and check lists presented in the Flight Manual ("Dash 1").

3. To evaluate backup/emergency fuel management procedures while on the ground.

4. To determine fuel transfer rates.

5. Specific objectives requested by the Program Office.

Test Conditions/Procedures. The ground fuel transfer test will be conducted on any aircraft which has a manual fuel balancing capability and on aircraft with automatic balancing capability when feasible. The aircraft will be parked in an attitude representative of normal flight and will be connected to the ground power ground servicing equipment usually associated with pre/post flight operations.

The ground transfer test will normally be conducted concurrently with the ground refueling/defueling evaluation. It is conducted before the inflight fuel transfer test using the proposed in flight procedures. A fuel imbalance whose asymmetric moment is within the landing trim control capability of the aircraft will be created. It will then be corrected using the procedures prescribed in the Flight Manual. Fuel quantity in each tank before and after transfer and the required time to transfer will be recorded. The fuel transfer sequence will be evaluated for practicability, ease of accomplishment, logical sequence of checklist items, potential problem areas and safety.

If feasible without engines running, the fuel sequencing will be simulated by defueling and evaluated for accuracy, center of gravity control, practicability and ease of accomplishment, logical sequence of check list items, potential problem areas and safety.

Data/Support Requirements. The following support is required to satisfy the test objectives of the ground fuel transfer evaluation:

1. Indicator calibrations, in accordance with maintenance procedures.

2. Fuel truck and defuel adapters.

3. Fire truck

4. Fuel system parameter instrumentation package (in aircraft).

5. Computer reduction of data.

Necessary data parameters are summarized in Table 9A (Page 74).

Ground Evaluation of Operation with Failed Boost-Pumps and of Automatic Fuel Sequencing:

Test Objectives These are:

1. To perform a preliminary evaluation of fuel feed with boost pumps failed, as a precaution before proceeding to flight test.

2. To perform a preliminary evaluation of fuel sequencing when this is automatic and cannot be tested without running the engine(s).

3. Any specific objectives requested by the Program Office.

Test Conditions and Procedures. For these evaluations, which are in part precautionary prior to flight test, the engineer should make maximum use of data available from contractor flight or simulator tests.

For the boost pumps failed tests a ground run of all engines will be conducted:

a. With the normal boost pumps turned off.

b. With the backup system (emergency pump, pressurization) also off, if the back-up mode is not gravity feed.

The boost pump inoperative ground test will consist of an engine run on all engines similar to an installed trim run. After engine start, the fuel tank boost pump(s) supplying each engine will be turned off or, if the pump operates automatically, its circuit breaker will be pulled. Power on all engines will then be increased incrementally from idle to maximum (takeoff) power, including afterburner. At least four intermediate increments will be used, with at least one minute of stabilization at each, and the throttles then retarded smoothly to idle. During each increment, the person operating the engines will observe the engine indicators, especially fuel flow for fluctuations or other abnormalities. Should a fluctuation develop, the associated boost pump will be turned on. If the fluctuation persists all power will be smoothly retarded to idle. If the boost pump has been rendered inoperative by a circuit breaker that is not in the cockpit, power will be immediately and smoothly retarded to idle. The run sequence will be repeated at least once more to assure consistent results.

Tests of automatic fuel sequencing will be made with extenal tanks on and filled as appropriate and with the aircraft in an attitude representative of flight. A run-up, take off and flight profile will be simulated which will use fuel down to normal minimums.

Data/Support Requirements:

1. Support as for engine trim runs

2. Fuel system parameter recording as shown in Table 9A (in aircraft).

3. Computer reduction of recorded data.

Ground Evaluation for Aerial Refueling:

Test objectives These are:

1. To perform fit and functional tests of the aerial refueling system and ensure receiver/tanker compatability prior to flight test.

2. To determine fuel flow rate and pressures during fuel transfer.

3. To determine surge pressures when the tanker fuel pumps are turned on, at shut-off of individual tanks (if applicable) and at fuel shut-off when the receiver is full.

4. To evaluate lighting for night refueling.

5. Specific objectives requested by the System Program Office.

Test Conditions/Procedures. The aerial refueling qualification include ground tests and evaluations using the test aircraft as receiver and an instrumented tanker. (AFFTC Regulation 80-3).

Boom Type Refueling Systems Prior to conducting the flight tests the aerial refueling system will be ground checked. The fuel system, i.e., lines, manifolds, valves, etc., will be incrementally pressure tested with fuel to a design value specified by the airframe contractor. This value usually exceeds 180 psig. During this test, all components will be verified to be free of leaks and all bypass or pressure relief valves function properly. Following the pressure check, all manifold drains and pumps will be verified to function properly and effectively.

After completing the pressure check, the refueling receptacle will be functionally checked with a test adapter (MIL-T-83323 or appropriate adapter) to determine that the latches open and close properly, that the disconnect coil works properly for disconnect commands from the receiver pilot or copilot and from the boom operator, that all refueling lights and indicators in the cockpit work properly and in the correct sequence, and that the secure intercom system functions properly.

After the functional check of the receptacle, a ground test will be conducted using actual hook-up with the tanker aircraft. PAD 19 at Edwards as well as a pad at Carswell AFB, (General Dynamics - Ft Worth) have sufficient differential elevations so that the tanker can be parked with a fighter/attack type receiver aircraft below and behind the tanker. This allows contact with the receiver at approximately 10 to 12 degrees boom elevation. If an elevated pad is not available, or if a large receiver is to be tested, fuel transfer between tanker and receiver can be accomplished using a ground fuel transfer hose assembly kit. This, however, is only available for the KC-135 at this time (Reference TO KC-135(K)A-2-5-1). The pressure disconnect switch on the receiver must be deactivated during transfer tests to prevent disconnect when the receiver is full.

Fuel transfer will be accomplished to determine flowrate, surge and steady state pressures. Small amounts of fuel will be transferred into various combinations of receiver tanks using an increasing number of tanker refueling pumps. These transfers will be characterized by several different begin-/and end- flow receiver quantity/tank configurations in order to generate fuel pressure surges within receiver's fuel system. During each of the surge generating sequences it will be necessary to monitor manifold fuel pressure indicators or recorders on both the tanker and the receiver to determine that the surges do not exceed specified or design values.

Based on this a determination will be made of the maximum number of tanker pumps that should be used. Finally, the receiver will be filled to capability and the surge pressure at fuel shut-off observed.

An evaluation will be made of the suitability of the lighting under or simulated night conditions (e.g., in a hanger) with the receiver and tanker in as nearly correct relative positions as is feasible. This evaluation will be made by tanker and receiver crews, usually with participation by the Human Factors branch of Flight Test Engineering

Probe/Drogue Type Refueling Tests. Ground tests for probe/drogue systems are the same in principle as those for boom type refueling systems. They will similarly include fit and functional tests, determination of flows and surge pressures and the maximum number of tanker pumps that can be used and a night lighting evaluation.

Support Requirements. These include

1. Fuel truck/refueling pit support and specialized refuel/defuel adapters.

2. Fire truck.

3. Still photography (color plus black and white).

4. Instrumented tanker aircraft.

5. Pad with differential tanker receiver elevations (if feasible) for boom refueling.

6. Fuel systems instrumentation package in receiver (if available).

7. Computer data reduction (calibration and plotting of time histories).

8. Required data parameters summarized in Table 9A.

9. Facilities for the night lighting evaluation.

FLIGHT TESTS OTHER THAN AERIAL REFUELING

Tables 11 and 12 (Pages 80 and 81) provide an overview of the types of flight conditions to be explored and the fuel system tests to be conducted in those conditions. Basically, the objective is to validate nominal fuel system operation over the whole of the permissible flight envelope and degraded operation over appropriately reduced envelopes. These envelopes will be defined in the Flight Manual ("Dash one").

Flight Conditions:

The flight conditions listed in the Tables essentially apply to all classes of aircraft, except that aircombat maneuvers do not apply to large bombers or transports. Proper fuel flow in a sideslip or at less than one "g" is, however, very important to such aircraft.

A first step in flight planning is to identify quantitatively the flight conditions required, using the Flight Manual and available performance data. In a Combined Test Force operation these conditions may have already been selected by the contractor, and reviewed by the System Program Office, but in this case the AFFTC engineer must also review them to satisfy himself that they are adequate. The contractor System Operational Analysis should obtained reviewed by the flight test engineers.

Failure Modes:

Paragraph 3.5.2.1 of MIL-F-38363B states that: "A complete fuel system failure analysis shall be conducted and a report prepared. The analysis shall encompass any component or system failure that has any effect on the fuel system and any fuel component or system failure that affects any other aircraft component or system. The study shall not be limited to single failures but should account for multiple failures in critical flight modes and during emergency conditions".

The flight test engineer should examine the fuel subsystem and the Flight Manual to identify failure modes and determine what combinations should be tested. It is not feasible to write universal instructions for this task in a readable form. Table 13 (page 82 illustrates the approach to the task by showing the tests performed on the F-15 in a variety of conditions of partial failure. It is important to approach the task with both thoroughness and imagination. As an example, when the F-15 system reverted to gravity transfer from the fuselage transfer tank, it was found that a fairly nose-high attitude was necessary to provide an adequate transfer rate to the feed (main) tanks. A computer simulation of the fuel subsystem may be of substantial assistance in identifying potentially critical areas.

Functioning in Climbs Dives and Maneuvers:

These tests are to evaluate the nominal functioning of the fuel system (i.e., no component failures) in stressing parts of the permissible aircraft flight envelope and also operation with partial failure. The aircraft is to be able to complete its mission after a single failure and to be recovered after a double failure.

Test Objectives. These are to:

1. Demonstrate proper feed and transfer in climbs, rapid descents, and all permissible stressing maneuvers.

2. Demonstrate proper pressurization and venting.

3. Demonstrate proper functioning of explosion suppression subsystem, if of inert gas type.

4. Any specific objectives requested by the Program Office.

Test Conditions and Procedures. Flight test and fuel system operating conditions will include the following:

1. Sustained normal climb at MAX power: nominal and feed boost pump off.

2. Sustained normal climb at MIL power: nominal and feed boost pump off.

3. Fast idle power descent: nominal with one pressurization system failed.

4. Maximum permissible sideslip, pushover, maximum roll rate, inverted flight if permitted: nominal and feed boost pumps off.

5. In high performance aircraft, zoom climb and dives: nominal and one pressurization system failed. Extreme attitudes must not be entered for fuel system tests until these attitudes have been cleared from a flying qualities standpoint.

6. In aircraft with an attack function, simulated weapons passes: nominal and feed boost pumps off.

Operation at take off power with boost pumps off will be checked by ground test. Take off and landing will be performed with all pumps on. On aircraft with automatically operating pumps, special switches must be installed in the cockpit. After setting up test conditions the test pump will then be turned off.

Operation boost off will be demonstrated up to the Handbook limits - for example in supersonic flight at low altitude. Limit conditions should always be approached by a build up procedure.

On three - or four-engine aircraft the test will be done with an inboard (center) pump feeding one engine turned off, then repeated with an outboard pump feeding another engine turned off. A full throttle climb or maximum performance climb will be performed from approximately 5000 feet pressure altitude to the maximum operating altitude for the aircraft. The engine instruments, especially fuel flow, will be monitored for fluctuations or other abnormalities attributable to insufficient fuel. Should fluctuations occur, the boost pump will be immediately turned on, the climb terminated and level flight attained. The aircraft will then descend with the pump off to a typical cruise altitude and perform maneuvers such as turns. simulated weapon delivery/ strafing passes, simulated approaches and go-arounds. Following these maneuvers the aircraft will perform a partial power penetration type descent to landing pattern altitude.

Tests in fast climbs and dives should include a build up program to check tank pressurization and venting with increasingly rapid rates of altitude change, before testing at the maximum rates allowed by flight limitations.

Data/Support Requirements. The following support is required:

1. Fuel system instrumentation package in the aircraft, recording parameters as shown in Table 9B, (Page 75) with magnetic tape recording or equivalent.

2. Computer reduction of data

Functioning and Fuel Management in Steady Level Flight:

These tests evaluate the functioning on the fuel system in long range cruise in the nominal operating mode and with various types and degrees of degradation by component failure. Particular attention is paid to satisfactory feed, tranfer and center of gravity control, to crew workload, and to simplicity and clarity of operating procedures.

Test Objectives. These are to:

1. Demonstrate satisfactory feed, transfer and center of gravity control in nominal operation and with various levels of component failure.

2. Demonstrate low fuel warning

3. Specific objectives requested by the System Program Office.

Test Conditions and Procedures. Feed, transfer and center of gravity control will be observed and evaluated throughout the test program. Degraded operating modes will have been identified as part of the preliminary planning of the flight test program. Tests in these modes will be scheduled in combination with other flight tests as opportunity arises.

Flight conditions will be primarily long range cruise but will include all level flight operating conditions encountered in normal operations. The fuel system operating modes will include, for example:

1. Failed main (feed) tank booster pumps

2. Failed transfer pumps

3. Manual backup control of cg where the nominal mode is automatic.

These tests will be scheduled into the total flight test program in combination with other tests.

Data/Support Requirements. These are:

1. Instrumentation data package with parameters shown in Table 9B (Page 75).

2. Computerized data reduction

Fuel Transfer tests:

In addition to the above tests, tests will also be made specifically to evaluate correction of lateral or longitudinal center of gravity by fuel transfer.

Test Objectives. These are:

1. To determine inflight fuel transfer rates.

2. To evaluate fuel management procedures and checklists presented in the Flight Manual.

3. Specific objectives requested by the Program Office.

Test Conditions/Procedures. The inflight fuel transfer test will be conducted in level flight at cruise airspeed and altitude. A fuel imbalance whose asymmetric moment is within the landing trim control capability of the aircraft will be created, then corrected by transferring fuel from tank or from wing to wing.

The procedure for the inflight fuel transfer test will be the checklist presented in the Flight Manual. A nominal fuel imbalance will be created either by transferring fuel from wing to wing or by asymmetric fuel burnoff. The pitch or roll moment created by this imbalance will be within the pitch or roll trim capability of the aircraft to permit a safe landing. These moments are presented in the performance section of the Flight Manual. Once the asymmetry is created, it will then be corrected by transferring fuel from tanks in the "heavy" wing to tanks in the "light" wing, forward to aft, or inboard to outboard, etc. If there are several ways to correct the asymmetry, multiple tests will be conducted. Fuel quantity in each affected tank will be hand recorded before and after the transfer, and the transfer sequence itself will be timed. In addition, the transfer sequence will be evaluated for ease of accomplishment, impact on otherwise existing aircrew workload, practicality, logical sequence of checklist items, potential problem areas and safety.

Data/Support Requirements.

1. Instrumentation data package with parameters summarized in Table 9B (Page 75).

2. Computer reduction of data.

Fuel Jettison Evaluation:

Test Objectives. These are:

1. To evaluate the capability and safety of fuel jettison.

2. To determine fuel jettison rates.

3. To evaluate the checklists presented in the Flight Manual.

4. Specific objective requested by the Program Office.

Test Conditions/Procedures. Fuel jettison will be conducted over unpopulated areas at a high enough altitude that jettisoned fuel will have evaporated before reaching the ground. Fuel will be jettisoned at several airspeeds during level flight and during gentle turns, ascents, and descents. Care will be taken not to fly through the stream of jettisoned fuel.

A nominal amount of fuel will be jettisoned during each test using the Flight Manual procedure. Jettison will first be performed in level flight and at one airspeed. During each run, a different number or combination of tanks will be jettisoned from and the flowrate determined. The number of pumps per tank recommended by the Flight Manual will be utilized. After sufficient runs have been made to determine the relationship between number of tanks and jettison flowrate, several representative test points will be rerun using a different (usually less) number of pumps per tank. Following these test points, the most optimum tank/pump configuration will be rerun at several different airspeeds in level flight, then this configuration will be rerun at the most optimum airspeed during turns and gentle ascents/descents. Pylon or accessory (external) tank jettison will be evaluated as a part of the Weapons Delivery Evaluation.

Data/Support Requirements.

1. Photo Chase

2. Instrumentation data package with parameter summerized in Table 9B.

3. Computer reduction of data.

Functioning with Cross Feed and During Transients:

Test Objectives. These are:

1. To demonstrate that any/all engines can be fed satisfactorily from any tank(s).

2. To demonstrate that fuel flow to one engine can be varied without affecting fuel flow to other engine(s).

3. To demonstrate satisfactory operating during changes in engine setting, boost pump operations and other pertinent operating conditions.

4. Any specific objectives requested by the Program Office.

Test Conditions and Procedures. These are summarized in the following table:

Test Conditions and Procedures. These are summarized in the following table:

Flight Condition	Power Setting	Test Procedure
Low speed, low altitude High speed, low altitude High speed, high altitude	Low High MAX	Each boost pump cycled and off Various cross-feed, including all engines from one tank
High speed, low altitude	High	Cycle each engine MIL to MAX, IDLE to MIL
High speed, high altitude	High	Cycle each engine MAX to MIL to MAX

Data/Support Requirements. There are

1. Instrumentation data package with parameters summarzied in Table 9B (Page 73).

2. computer reduction of data

AERIAL REFUELING QUALIFICATION

Aerial refueling tests differ from most other evaluation tests in that they involve inflight compatibility between the receiver aircraft under test and a small number of existing tankers (KC-135, KC-10, KC-130). All large Air Force aircraft use the boom technique, but aircraft with a gross weight below 75000 pounds may use the probe/drogue technique. Procedures for AFFTC Aerial Refueling qualification tests are defined in AFFTC Regulation 80-3.

Boom Aerial Refueling:

With this technique the receiver pilot maneuvers into position, after which actual contact is completed by the boom operator on the tanker.

Test Objectives. These are:

1. To determine the aerial refueling flight envelope.

2. To determine the aerial refueling contact and disconnect envelopes.

3. To verify that all components function satisfactorily

4. To determine fuel transfer pressures and flow rates.

5. To evaluate emergency, override and backup modes of aerial refueling including stiff boom contacts and tension disconnects.

6. To evaluate tanker/receiver compatibility.

7. To evaluate suitability of night lighting.

8. Specific objective requested by the Program Office.

Test Conditions/Procedures. The aerial refueling qualification will consist of ground tests described earlier and an inflight evaluation using the test aircraft as receiver and an instrumented tanker. The KC-135 and the KC-10 tankers used at AFFTC have strip chart instrumentation to give real time information to the test engineer, as well as tape recorded data.

The inflight evaluation will consist of formation flying, hookups and disconnects at several airspeeds and altitudes common to the flight envelopes specified in the Flight Manuals of both the receiver and the tanker. Minimum test altitudes should provide adequate ground clearance for emergency breakaway maneuvers which involve rapid changes in airspeed and altitude in order to separate the aircraft rapidly and safely. The exploratory tests will be conducted under VFR conditions with as optimum prevailing weather as possible.

After establishment of operating envelopes, however, the impact of light-to-moderate and moderate-to-heavy turbulence on the time to accomplish hookup and on crew workload should be assessed (MIL-F-38363, para 4.5.6.2.2d). Also, if the receiver aircraft has a control augmentation system, hookup shall be evaluated with various parts of that system inoperative.

Flight Envelope Evaluation This part of the aerial refueling evaluation will be done concurrently with the aerial refueling portion of the Performance and Handling qualities evaluation. To verify the flight envelope, the two aircraft will first be flown in the refueling formation with the receiver in the observation position, then moving up at various rates of closure to the precontact and contact positions without actually making a hookup. The receiver will then back away from the tanker at various rates of separation. The pilots of both aircraft will comment as necessary on handling qualities. This procedure will be repeated with both aircraft flying at various combinations of airspeed, altitude, gross weight and configurations until an optimum airspeed/altitude range is found where the two aircraft are compatible.

Contact and Disconnect Envelope Evaluation After the optimum aerial refueling airspeed and altitude have been determined, contact and disconnect envelopes will be determined.

The boom of the KC-135 tanker is equipped with limit switches which automatically initiate a disconnect when boom azimuth reaches or exceeds 15 degrees left and right of the tanker centerline, when boom elevation reaches or goes outside of the range of 20 to 40 degrees below the tanker's fuselage reference line or when the boom extension is less then 6 feet or greater than 18 feet. Actual working limits on azimuth for the KC-135 are ± 10 degrees. (Note that "elevation" is measured downward from the tanker water line, as is illustrated in Figure 8 page 90). The KC-10 boom has a wider azimuth envelope and longer extensions (5 to 22 feet, giving an extended length by 680 inches instead of 551 inches). The KC-10 also has a rate initiated disconnect. The optimum contact position is usually 30 degrees boom elevation and zero degrees azimuth. Contacts are accomplished initially within a conservative contact envelope, which is then expanded in an orderly and conservative manner in conjunction with the disconnect envelope expansion, as described below.

To establish the disconnect envelope, the receiver moves slowly after contact to stabilize at the desired disconnect position. It is imperative for repeatability that slow movements and stabilized disconnects be made by the receiver. In addition, no more than 5-degree increments between test points should be established and adhered to. At the outer extremes of the boom disconnect envelope 2- to 3-degree increments are considered more practical. If at any point a binding between the boom nozzle and the receptacle is encountered, those test points towards the more extreme part of the envelope from the point at which difficulty was experienced, will not be attempted since this could result in damage to the nozzle and/or the receptacle. Boom loads and position at disconnect will be recorded for a quantitative evaluation.

After establishment of the envelopes the impact of deactivating parts of the control augmentation system, if any, on the receiver aircraft will be assessed. An assessment will also be made of the impact of turbulence on hookup time and crew workload.

<u>Fuel Transfer Rate and Pressure Surge Evaluation</u>

Fuel transfer will be accomplished to determine flowrate and pressures. Small amounts of fuel will be transferred into various combinations of receiver tanks using the maximum number of tanker refueling pumps determined during the ground test phase. These transfers will be characterized by several different begin-/and end- flow receiver quantity/tank configurations in order to generate fuel pressure surges within the receiver's fuel system. During each of the surge generating sequences it will be necessary to monitor manifold fuel pressure indicators or recorders or both the tanker and the receiver to determine that the surges do not exceed specified or design values.[3]

Following completion of the surge test, larger amounts of fuel will be transferred for predetermined periods of time, such as 2 or 3 minutes, recording the amount of fuel transferred. Multiple transfers will be necessary, utilizing several combinations or numbers of receiver tanks in order to determine the relationship between flowrate and number of receiving tanks. Following this, the effect on flowrate and pressure surges will be determined using the worst-case pressure surge or maximum flowrate case determined above and reducing the number of tanker pumps operating in order to reduce the surge pressure. The receiver will than be filled to capacity to verify top off and automatic shut-off.

Reverse Refueling Reverse refueling will be performed with larger aircraft which have a boost pump capacity to reverse refuel tanker aircraft. The aircraft will perform a normal hookup, and a small amount of fuel will be transferred from the tanker to the receiver to verify that the nozzle-receptacle connection is working properly. To accomplish reverse refueling the boom operator normally maintains retract boom pressure (to verify that the nozzle-receptacle connection is working properly at the time of the test); however, the AFFTC tanker has a fuel bypass switch that also performs this function. The tanker will then turn off its pumps and the receiver will turn on the number of fuel transfer pumps usually associated with maximum deadhead pressure. The crew of both aircraft will then monitor fuel quantity for a notable change. In addition, the tanker crew will monitor boom fuel line pressure for back pressure indicative of reverse fuel flow. Following this practical demonstration of reverse refueling, multiple reverse fuel transfers will be performed for a timed period such as 2 or 3 minutes using different combinations of receiver tanks and numbers of pumps per tank to determine the relationship between flowrate and the number of supplying tanks/pumps per tank.

[3]If an uninstrumented receiver is being used, pressures will be monitored only on the tanker.

Emergency/Backup Mode Operation Aerial refueling will be performed with the system relegated to alternate or emergency modes. This will be accomplished after completion of the normal mode tests such as automatic envelope verifications, fuel transfer and surge tests, and flight envelope verifications. The emergency or alternate mode operation includes the following:

1. Manual door opening

2. Emergency boom latching (override)

3. Stiff boom refueling

4. Tension disconnects

5. Independent disconnect, if applicable

Following the fuel transfer and surge tests, stiff boom refueling will be accomplished. Stiff boom refueling is an emergency mode in which the receiver does not have normal or backup control power available to the aerial refueling system for boom latching. To accomplish the test, the receiver's aerial refueling door will be opened manually if necessary, but the powered system, i.e., latches, ready lights, etc., will be turned off. A normal hookup will be performed, except that the boom operator will maintain the contact using tanker hydraulic pressure to force the boom nozzle into receptacle. A small amount of fuel will be transferred to demonstrate the capability. Rapid release and reapplication of boom extend pressure by the boom operator during fuel transfer in this mode produces pressure surges and simulates stiff boom refueling in turbulent air. Fuel transferred, flowrate and leakage will be monitored and compared to a normal hookup.

The boom has limit switches at the inner and outer limits of extension which initiate an automatic disconnect to protect the boom should the receiver inadvertently move to either of these locations. In the event of a receptacle latch failure in the latched position, the automatic disconnect or a manually initiated disconnect will be ineffective. In this case, the receiver must back slowly away from the tanker until sufficient tensile force is generated to overcome the latching hydraulic pressure. The hydraulic cylinder which operates the latches should be equipped with a bypass valve which allows the latches to be forced open without damage to either the nozzle, receptacle, or adjacent aircraft structure.

To perform the tension disconnect test the boom operator will disable the outer limit switch and the receiver air refueling amplifier will be switched to OVERRIDE (or the receiver should be configured with a jumper wire to override the "not in" switch) so that the latches will not open automatically as the nozzle is pulled out past the "not in" switch's plunger. A tension disconnect will then be performed by slowly backing away from the tanker at zero azimuth and 30 degrees boom elevation until a disconnect occurs. Instrumentation on the tanker will tell how much tensile force required to extract the nozzle. This force must be within the limits of military specification MIL-F-38363. Tension disconnects will be repeated several times varying the azimuth and elevation angles for comparison with center-of-envelope disconnects.

With the KC-10 tanker the "independent disconnect" system can be used instead of tension disconnect. To evaluate this, the receiver should again switch the air refueling amplifier to OVERRIDE. The independent disconnect system should then be able to effect disconnect.

Night Operation Night aerial refueling will be evaluated after daylight procedures have been established. Several hookups and disconnects will be performed and the refueling sequence will be evaluated by a cross section of air crews of both aircraft in the following areas:

1. Similarity of approach, hookup, disconnect, and backaway procedures to daylight operations.

2. Effectiveness, placement, brightness/dimness and aiming of receptacle and formation lights.

3. Availability and usefulness or visual references, vertigo tendencies, etc.

4. Distractive light sources within the receiver cockpit such as instruments, radar scopes, etc.

Data/Support Requirements The following support is required to satisfy the test objectives of the aerial refueling evaluation for receptacle aircraft:

1. Motion picture photography (24/48/250 frames per second color, 16mm) from the tanker and from the chase aircraft.

2. Still photography from the tanker and from the chase aircraft Table 9C (Page 77).

3. Chase aircraft

4. Instrumented tanker aircraft

5. Fuel system parameter instrumentation package in receiver aircraft), preferably magnetic tape, with receiver parameters shown in Table 9B (Page 75).

6. Computerized reduction of data.

Probe/Drogue Aerial Refueling:

Test Objectives. These are:

1. To determine the aerial refueling flight envelope.

2. To determine contact and disconnect envelopes.

3. To verify that all components function satisfactorily.

4. To determine fuel transfer pressures and flow rates.

5. To evaluate emergency aerial refueling procedures.

6. To evaluate tanker/receiver compatability.

7. To evaluate suitability of night lighting.

8. Specific objectives requested by the System Program Office.

Test Conditions/Procedures. The aerial refueling qualification will consist of ground tests described earlier, followed by an inflight evaluation using the test aircraft as the receiver and a KC-130, an instrumented KC-135 equipped with the Boom-Drogue Adapter (BDA) kit or an instrumented KC-10.

Flight Envelope Evaluation The flight envelope verification tests for probe and drogue aircraft will be done using basically the same procedure as for receptacle aircraft except that with the Boom Drogue Adapter Kit all allowable KC-135 boom elevation angles will be evaluated for hookup.

Contact/Disconnect Envelope After an optimum trail position and airspeed has been determined for hookup, actual contacts and disconnects wll be performed. When the KC-135 is used, the boom can be moved to provide various azimuth and elevation angles for disconnect. These should be approached in 5-degree increments. The receiver must actually position the drogue when the KC-130 or KC-10 aircraft is used and this must also be approached cautiously to prevent probe damage. Both inner limit (auto retract) and outer limit (tension) disconnects should be accomplished. Probe loads will be recorded. Contacts will be made in smooth, light and moderate turbulence.

Fuel Transfer Rate and Pressure Surge Evaluation Fuel transfer will be accomplished to determine flow rate and pressures. The number of pumps and flow rates determined during the Ground Tests will be used. Pressure surges during disconnect while refueling and at shutoff when the receiver tanks are full will be evaluated and the number of pumps used reduced if these surge pressures exceed limits. Time to completely fuel the receiver from minimum fuel to full will be determined. Pressure surges due to disconnect of a second receiver aircraft on the opposite drogue of a KC-130 aircraft will be evaluated.

Night Operation After daylight tests have been conducted the evaluation of night operations should be made within the previously determined limits. All lighting, ease of contact, and other appropriate characteristics of night aerial refueling will be observed and compared to day operations.

Data/Support Requirements. The following support is required to satisfy the test objectives of the Areial Refueling Qualification for Probe/Drogue Aircraft:

1. Motion picture and stills from tanker & chase aircraft.

2. Chase aircraft.

3. Instrumented Tanker Aircraft KC-130, KC-10 or KC-135 (Table 9C).

4. Fuel system parameters instrumentation package (in receiver aircraft), preferably magnetic tape with data parameters shown in Table 9B (Page 75).

5. Computer reduction of data.

ALL-WEATHER TESTS

Test Objectives:

The test objectives are:

1. To verify that the fuel system operates without deficiencies over the full range of environmental conditions without undue attention from the crew.

2. To verify serviceability and maintainability over the full required range of environmental conditions.

3. Any specific objectives requested by the System Program Office.

Test Conditions and Procedures:

Tests will usually be conducted in the McKinley Climate Laboratory at Eglin AFB and in the field in Arctic (eg Alaska), hot (eg El Centro) and possibly tropic conditions (eg Panama). Detail of these facilities and of climatic test procedures are given in Reference 3.

These tests will validate normal operation under the extreme conditions by performing simulated or actual normal operational profiles, including ground refueling and defueling and aerial refueling. Tests will also include:

1. Ground and flight tests with failed boost pumps.

2. Checks of adequate fuel expansion space and venting and fuel drain.

3. Checks of functioning of refueling doors etc, after icing or in freezing conditions after rain.

4. Check of sealing under extreme temperatures.

5. Tests with alternate fuels.

6. Tests of any components suspected to be susceptible to extreme weather conditions.

Aircraft will be serviced with fuel which has been "soaked" at the appropriate temperature in the truck. Summer field tests will include take off and maximum climb with fuel as hot as possible, but at least 110° F, with each engine operating from its normal supply. Test requirements will be defined in Test Information Sheets, which will be consolidated into a Test Integration Plan for each of the test sites by the climatic test engineer.

Climatic Laboratory Tests. These are made with the aircraft tied down in the hangar but otherwise are designed to parallel flight operations as closely as possible. Preflight, engine start, system activation, aircraft shutdown, and post flight and refueling are conducted in as close accordance with standard procedures as possible. Environmental temperatures will be covered as called for in the aircraft design specification. Cold weather operation of all features (such as the refueling receptacle door) will be checked.

Field Tests. These similarly consist of the conduct of normal operations and mission profiles using standard procedures, the objective being to evaluate system suitability and operating procedures under extreme operating conditions.

For high performance aircraft which use the fuel to cool oil or components, tests will be included in which hot soak is followed by high speed flight at low altitude.

Data/Support Requirements.

Support requirements are:

1. Use of the Climatic Laboratory and associated support.

2. Field test site support.

3. Normal operational support as called for in the proposed standard procedures.

4. Photographic support (16 mm color, and stills in color and in black and white).

5. A portable weather recording system for field tests.

6. On site data reduction.

ALTERNATE FUEL TESTS

Operation on alternate fuel is now required for interoperability with NATO (Europe, JP8) and the US Navy (Pacific, JP5). To ensure interoperability with NATO the alternate fuel test program should be designed to validate operation throughout the flight envelope, including operation in degraded modes. This, however, requires repetition only of normal operational profiles and selected degraded configurations which could be affected by the change in fuel.

Alternate fuels tests on the subsystem will be part of a program testing system functioning, including a substantial amount of engine testing. Only the fuel subsystem part of the program is discussed here.

Test Objectives:

1. To evaluate fuel subsystem operation on alternate fuels.

2. To identify differences in operating characteristics of the fuel subsystem with alternate fuels as compared to operation on the primary fuel.

3. To check for leaks.

4. Specific objective requested by the System Program Office.

Test Conditions and Procedures:

Alternate fuel operation will be evaluated for limited periods of time. Ground tests will be conducted under average and All-Weather conditions. These include temperature and pressures approximating standard day, tropical or hot day, and temperatures below freezing. Pretest-cold-soak-and during-test conditions will be the same as those in the primary fuel tests.

Inflight tests will be conducted under the same approximate conditions as those in the primary fuel tests, but on a spot check basis. Level flight test points will be performed first, then a limited number of maneuvering flight test points will be evaluated.

Extended cruise test data on JP4 will be reviewed to check the possibility of alternate fuels getting too cold in the tanks after long exposure.

Ground Tests. These should include:

1. Weight and balance measurements and fuel quantity system calibrations using the alternate fuel

2. Checks for fuel containment

3. Fuel transfer transfer tests after cold soak (high fuel viscosity)

4. Tests with boost pumps inoperative, after cold soak, in preparation for flight tests

5. Selected tests with crossfeed after cold soak.

Flight Tests. These should include the following tests after cold soak and after hot soak on the ground:

1. MAX and MIL power climbs with nominal fuel system operation

2. MAX and MIL power climbs with single boost pump failure

3. Cruise with nominal operation, with selected crossfeed, and in all degraded modes validated with the baseline fuel

4. Checks of functioning in any conditions which tests

with the baseline fuel suggest might be critical

Data/Support Requirements:

The following support is required to satisfy the test objectives of the alternate/emergency fuel evaluation:

1. Alternate fuel servicing.

2. Procedures for flushing JP4 out of tanks and engine (eg engine fuel controls).

3. Fuel samples and analyses from both truck and aircraft every time the aircraft is refueled.

4. Fuel subsystem instrumentation package with parameters summarized in Table 9A and 9B (Page 74-75).

5. Computer reduction of data.

DATA MEASUREMENT, ANALYSIS AND EVALUATION

New type aircraft will usually have fuel systems instrumented to the requirements of MIL-F-38363 and the System Program Office. Parameters pertinent to the specific tests are summarized in matrix form in Tables 9A through C. Current calibrations must be available for all instrumentation from a competent source. Since fuel system tests are primarily to verify that the system meets requirements, extreme precision is not normally required. It is, however, important that the frequency response of the instrumentation systems measuring line pressures (pressure pickup plus processing) is high enough to measure transients correctly. The engineer should review all calibrations to ensure that they cover the appropriate ranges, do not exhibit excessive hysterisis and are in general, acceptable.

The overall objective of the tests is to evaluate the fuel system as a subsystem of an operational aircraft and to determine if any serious problems or deficiencies exist. This evaluation will draw on qualitative comments of air and ground crews and on experience gained in tests flown for other objectives and/or on other aircraft as well as on data from tests specifically made to evaluate the fuel system.

The final report on the fuel subsystem evaluation will give a brief description of the fuel system and draw attention to leading particulars and to the basic logic of its operation. For each test the aircraft model, designation and serial number will be given. The general approach will be to describe each group of tests in turn, briefly list the relevant evaluation criteria and state whether these are met. These criteria must always include the overriding criterion of operational suitability as well as that of meeting specification requirements. If the fuel subsystem fails to meet a specification requirement it may still be considered operationally acceptable. Further, it may meet specification requirements and still be considered unsuitable for operational use.

When criteria are not met enough detail must be given to effectively define the short-fall. Tabular summaries will be given of the tests conducted with appropriate comment. Where appropriate, as in dynamic conditions in general, time history plots will be presented with attention drawn to the important parameters. Still photographs are an important and highly effective means of illustrating some types of problem. The engineer should ensure that appropriate photographic documentation is obtained.

Objectives, pertinent parameters, criteria and presentation recommendations for analysis, evaluation and reporting of each test are collected, for ease of reference, in Appendix D (Page 123).

REFERENCES

1. Military Specification, Fuel Systems, Aircraft General Specification For, MIL-F-38363B (USAF)

2. Aerial Refueling of Test Aircraft, AFFTC Regulation 80-3, 31 July 1979

3. All Weather Testing, AFFTC Systems Engineering Branch Handbook, Vol II, Chapter V

4. Military Specification, Turbine Fuel, Aviation, Grades JP-4 and JP-5, MIL-T-5624L 18 May 1979

5. Military Specifications, Turbine Fuel, Aviation, Kerosene Type, Grade JP-8, MIL-T-83133A 5 May 1976, Amendment 1, 4 April 1980.

6. Test Plan, AFFTC Regulation 80-12.

7. Test Plan Technical Review, AFFTC Regulation 80-13

8. Flight Safety Planning Guide for Flight Testing, AFSC Pamphlet 127-2

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Jet Fuel Termal Stability. William F. Taylor, Lewis Research Center, NASA TM 79231

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TABLE 1

AGENCIES INVOLVED IN FUEL SYSTEM FLIGHT TEST

TYPE TEST AGENTCY	DEVELOPMENT	DEMONSTRATE TO SPECIFICATIONS	FLYABILITY & MAINTAINABILITY	OPERATIONAL EFFECTIVENESS
Contractor	Yes	Yes	Assist	No
ASD/SPO	Direct	Check Compliance	Check	No
AFFTC	Liaison	Oversight & Independent Analysis	Primary Responsibilities	Yes
AFTEC	No	No	Yes	Primary Reponsibility
User Command	No	No	Advance Data Advice	Advance Data Advice
Air Training command	No	No	Advance Data	Advance Data
Logistics Command	No	No	Advance Data	Advance Data Advice

NOTES:

ASD = Aeronautical Systems Division

SPO = System Program Office

AFTEC = Air Force Test and Evaluation Center

* On some in-service aircraft Air Force Logistics Command as Program Manager will be the test requester rather than a System Program Office of Aeronautical Systems Division.

TABLE 2

Requirements[1] to Verify Normal Functioning Under All Design Operating Conditions

REQUIREMENT	IMPACT ON TEST PLANNING
3.5 Design and Construction: The fuel system shall be designed to supply fuel to the engines on an uninterrupted basis and shall function satisfactorily under all possible design operating conditions for the aircraft. The system shall in no way limit aircraft perfromance within allowable engine and aircraft operating limits.	Review flight envelope and system geometry to identify stressing conditions (high flow, sideslip, pushover, rapid climb and descent).
3.5.3.5 Center of Gravity Control: Normal sequencing of the fuel tanks shall be sufficient for maintaining the center of gravity of the fuel system from full to empty with all required payloads and flight speeds. It shall not be necessary to transfer fuel between tanks for the sole purpose of maintaining the center of gravity of the aircraft. Maintenance of a high minimum fuel load in order to effect a safe landing shall not be necessary. Manual controls shall be provided as a backup in the event of failure of the automatic controls.	Review system and control logic for potential problems, monitor functioning in all tests. Develop test to probe critical areas. Investigate critical conditions with offline simulation if available.
3.6 Fuel Available Uninterrupted under all aircraft ground and flight conditions without continuous crew attention. Immediate attention of pilot/flight engineer shall not be required under any condition, including failure. On aircraft normally operated by a single pilot system shall be fully automatic after activation.	As for 3.5

[1]Paragraph references are to MIL-F-38363B. The current version of this specification should be reviewed.

TABLE 2 (Continued)

Requirements to Verify Normal Functioning Under

All Design Operating Conditions

REQUIREMENT	IMPACT ON TEST PLANNING
Two indenpendent and isolated methods of moving fuel out of each tank (one for jettisonable tanks), each shall meet flow requirements for the particular tank for all altitudes, attitudes and maneuvers. If gravity flow meets requirements, only gravity flow required.	Test the possible combinations
3.6.1 Feed system shall provide satisfactory performance for all normal maneuvers up to aircraft service ceiling with each engine operating from its normal fuel supply.	Review flight test envelope and select appropriate stressing conditions.
3.8.1.1 Temperature of pressurization air shall not exceed limits of tank components/450 deg. F.	Monitor during flight program.
3.8.2.2 Inerting system shall be completely automatic and shall require no attention from the flight crew except for monitoring of high and low tank pressure indicator lights.	Monitor during flight program.
The system shall maintain oxygen content in the ullage space below 10 percent.	This should be demonstrated by the contractor on the "iron bird" simulation
3.8.2.2.4 Inerting gas shall dilute the oxygen content below 10 percent in all ullage and vent spaces and maintain a slight positive pressure at all times and for all operating conditions to prevent the entrance of air. The nitrogen shall fill the volume as fuel is used.	Direct measurement of oxygen content in flight test appears impracticable. Comparisons of inerting gas flow rate with rate of increase of pressure and volume in ullage spaces in dives will give an indication of adequacy.

TABLE 2 (Concluded)

Requirements[1] to Verify Normal Functioning Under

All Design Operating Conditions

REQUIREMENT	IMPACT ON TEST PLANNING
3.8.2.2.4.1 The inerting system shall remove oxygen from the air entrained in fuel to prevent the oxygen concentration from exceeding 10 percent during increases in altitude.	
3.8.2.2.4.2 Inerting gas shall pressurize the ullage and vent spaces during decreases in altitude to maintain a safe differential pressure between the tanks and ambient.	Check during fast climbs and descents.
3.8.2.2.6.1 Vent Valves. Vent valves shall control internal tank pressure within the limits of the aircraft.	
3.9 Fuel Vent Subsystem: The vent subsystem shall prevent siphoning and apillage of fuel and protect the fuel tanks from destructive pressure. Fuel spillage through the vent line during any in-flight maneuvers shall not exceed 0.05 percent of the fuel from any one tank or 1 gallon, whichever is smaller. There shall be no leakage when the aircraft is parked, during engine run-up or during taxing.	Monitor differential pressures and check for fuel spill during flight program, including stressing maneuvers and flight profiles (ref 3.5 and 3.6).
3.9.4 Vent pressures. For flexible non-metallic and light-walled metallic fuel cells, the vent outlet terminal shall be such that the pressure in the vented space in the fuel tanks is never below ambient pressure. For bladder type tanks the cell cavity pressure shall never be greater than the pressure within the tank.	Monitor differential pressures during tests, especially during fast descents.

TABLE 3

Requirements[1] for Operation with Component Failure

REQUIREMENT	IMPACT ON TEST PLANNING
3.5.2 Failure Concept. A single failure of a functional component of the fuel system shall not prevent completion of the mission. After two failures of fuel system or other subsystem supplying power to the fuel system the fuel system shall have the capability for recovery of the aircraft.	review system, identify failure modes, check system operation in these modes.
3.6.1.2 Gravity Feed. Fuel system shall be designed to consume all available fuel in the main tanks by gravity feed up to 10,000 ft with any fuel flow up to rated power with airframe fuel filters in by-pass or impending by-pass configuration.	Check for adequate flow rates within limits of flight safety. Should also be checked by contractor on simulator.
3.8.2.2.4.5 Pressures. At no time shall the positive or negative pressures in the fuel tanks and vents exceed the design pressure limits of the aircraft regardless of the failure of any component. In the event that the supply of nitrogen is depleted or that a malfunction of pressurization occurs, the inerted areas shall vent to ambient.	Check differential pressures during fast climbs and descents.

[1]Paragraph references are to MIL-F-38363B. The current version of this specification should be reviewed.

TABLE 4

Requirements[1] Associated with Specific Items,

Conditions and Functions

REQUIREMENT	IMPACT ON TEST PLANNING
3.5.3.2.1 Temperature Environment. The fuel system shall be designed to operate over the temperature range shown in Table 5.	Requires environmental test program.
3.5.3.2.2 Icing. Safety of flight shall not be jeopardized when operating with 0.75cc of free water per gallon in excess of saturation at 80 deg. F at the critical icing temperatures. The fuel system shall be capable of continuous operation with fuel initially saturated at 80 deg. F and cooled to any temperature down to -65 deg. F without anti-icing additives and without draining/cleaning system.	Part of environmental test program.
3.6.1 A normally separate main tank and feed system shall be provided for each engine. On multi-engined aircraft the independent systems shall be interconnected so that fuel may be delivered from any tank to any or all engines.	Check cross-feed combinations for satisfactory functioning at high powers.
Cutoff of any engine shall not adversely affect flow to the others.	Special test
3.6.2 Fuel transferred to a main tank is transferred to a main tank from internal transfer tanks the rate of transfer shall not be less than the maximum rate of fuel consumption of the engine in the military power condition.	Monitor during high power operation.
3.6.5 Feed and transfer surge requirement. Surge pressure shall not exceed 120 psig as a result of initiating or stopping intertank transfer or a result of decreasing the power setting of the engines.	Check all possible combinations.

[1]Paragraph references are to MIL-F-38363B. The current version of this specification should be reviewed.

TABLE 4 (Continued)

Requirements Associated with Specific Items,

Conditions and Functions

REQUIREMENT	IMPACT ON TEST PLANNING
3.9.3 Interconnected Vents. Fuel shall not be transferred through one tank vent to another tank. Several tank vents may be terminated at the same outlet location in the aircraft.	Monitor during test program.
3.13.1 Fuel Dump Rate. The fuel dump subsystem shall provide a minimum dumping rate per minute equivalent to 1 percent of maximum gross weight of the aircraft, and the aircraft shall be capable of dumping fuel to a safe landing weight in a maximum of 10 minutes.	Special test
3.13.2 Aircraft Controllability. The fuel dump operation shall not in any way adversely affect the controllability of the aircraft.	Monitor during 3.13.1
3.13.3 Dump Controls. It shall not be possible to dump fuel below reserve level (para 3.63) unless a second initiating action is performed by the operator.	Evaluate control layout -Results of special test 3.13.1
3.13.4 Fuel dump safety. During the fuel dump operation the fuel and fuel vapor shall clear all parts of the aircraft and no fire or explosion hazard shall result. Fuel or fuel vapor shall not impinge upon or re-enter any part of the aircraft.	Check during 3.13.1

TABLE 5

Fuel Temperature Versus Temperature Environment (MIL-STD-210A)

	Fuel Temperature		Ambient Air Temperature (Compartment)	
	Low Temp	High Temp	Low Temp	High Temp
Class I Fuel system which is not affected by fuel heating 1/	-65 deg F 2/	+135 deg F	- 65 deg F operating -80 deg F non-operating	+160 deg F
Class II Fuel system with aerodynamic heating or when fuel is used as a heat sink	-65 deg F 2/	Max fuel temp 3/ as determined by engineering design analysis	-65 deg F operating -80 deg F non-operating analysis	Max ambient 3/ temp as determined by engineering design

1/ Due to location in hot compartments, the temperature requirement for some components in a class I fuel system may exceed the temperatures specified. These components shall be identified and the maximum temperature specified.

2/ For fuels other than JP-4, the freezing point of the fuel should be used if higher than -65 deg F.

3/ Design analysis required as item 20.2a(2) of the appendix to MIL-F-038363B.

TABLE 6

Maintenance and Serviceability Requirements[1]

REQUIREMENT	IMPACT ON TEST PLANNING
3.6 Maintainability. All aircraft fuel system components shall be accessible for inspection, cleaning, and adjustment or replacement while installed on the aircraft, with tools normally found in a mechanic's tool kit and without removal of the engine, fuel tanks, or important parts of the aircraft structure.	Alert maintenance crew to critique maintainability under operational conditions.
3.6.6.1 Fuel boost pumps in fuel tanks of 1000 gallons or greater capacity shall be removable without draining the tank. Boost pump leads shall have disconnects.	Check maintenance manual. Verify by inspection of aircraft.
3.6.6.3 All fuel strainers shall be readily accessible and shall have sufficient clearance to permit easy removal of the cover and element. The filter or strainer shall be replaceable without draining the fuel from the system. Loss of the fuel in the assembly is acceptable.	Check maintenance manual. Verify by inspection of aircraft.
3.7 Aircraft Fuel Tanks. All fuel tanks shall be completely drainable while the aircraft is at ground attitude.	Requires physical check. Can be combined with defueling tests. (This requirement is rarely met completely).
Ample clearance shall be provided to enable removal of tank bladder cells, external tanks, internal tank components, tank access doors, tank inspection plates, and tank sumps without removing major structural	Review maintenance manual and actual physical layout. Perform test if in doubt.

[1] Paragraph references are to MIL-F-38363B. The current version of this specification should be reviewed.

TABLE 6 (Continued)

Maintenance and Serviceability Requirements

REQUIREMENT	IMPACT ON TEST PLANNING
components, engines, or engine accessories except cowling or air-frame access panels. It shall be possible to install and remove the fuel cells individually without interference with other cells, preferably through a non-stressed panel without requiring jack or other structural jigs.	
3.7.1.3.2 Sump Drains. Operation of the drain shall remove all of the collected sediment and water with a minimum loss of fuel.	Check as part of maintenance.
3.7.1.4 Access Doors. Each cell shall be provided with an access door or such size that the entire interior of the tank can be inspected and cleaned.	Perform physical check
3.7.6.1 Filler Openings. Shall be located to permit filling the tanks from outside the aircraft without overfilling into the expansion space. Special adaptors and funnels shall not be used. Scupper drains shall be used as necessary to prevent spilled fuel from entering any portion of the aircraft of engine compartment.	Check during ground refueling tests.
3.7.1.9.1 Tank Installation Time. The time required to completely remove and install a flexible internal (self-sealing or non-self-sealing) fuel cell in an aircraft shall not exceed 10 man hours.	Check, with operational style maintenance.
3.7.2.2.2 External Tanks - Installation Time. Time required to install an external tank shall not exceed 15 minutes.	Check, with operational style maintenance.

TABLE 6 (Continued)

Maintenance and Serviceability Requirements

REQUIREMENT	IMPACT ON TEST PLANNING
3.8.2.2.5 Nitrogen Servicing. The inerting system shall be capable of receiving liquid nitrogen at a minimum rate of 10 gallons per minute at pressures from 40 to 150 psig. The servicing connection shall be accessible from outside the aircraft, and the instrumentation necessary for servicing (such as quantity and dual pressure gauges) shall be visible from the servicing coupling.	Check during routine maintenance.
3.8.2.2.6 Nitrogen inerting system components. A checkout panel shall be provided to test all phases of inerting system for proper operation during preflight checkout.	Check funtioning during normal servicing.
Indicator light(s) shall be provided on the panel to signal when the vent valves have allowed air to enter the system.	
A means shall be provided as part of the aircraft to verify that the fluid serviced to the nitrogen inerting system is an inert gas.	Check functioning during normal servicing.
3.9.4.1 Vents - Pressure Checking. For aircraft where the vent system must be blocked during maintenance to pressure check the vent system or tanks, special ground support equipment (GSE) shall be designed for plugging the vent lines. The GSE shall be so designed that it will not cause damage to the tanks in the event it is left in the system at the conclusion of maintenance. The GSE shall have a stringer or marker to prevent leaving the GSE installed.	Check availability and suitability of GSE. Damage resistance should be demonstrated by the contractor.

TABLE 6 (Continued)

Maintenance and Serviceability Requirements

REQUIREMENT	IMPACT ON TEST PLANNING
3.11.1.6 Fuel Level Control Valve. A pre-check system which will check the operation of the fuel level control valves in the initial portion of each ground refueling shall be provided as an integral part of the aircraft. The precheck system shall operate on the float principle. The precheck system shall permit isolation of a failed level control valve.	
3.11.2 Gravity Refueling. It shall be possible to completely gravity refuel the aircraft without external power being applied to the aircraft. Each aircraft tank shall be capable of accepting a continuous flow rate of 200 gpm, except during topping up, without requiring any operation other than removing the filler cap and correcting the nozzle bonding plug. Tanks that can be refueled by overflow from an adjacent tank need not have a filler cap provided that the emergency defueling requirements (3.11.3) can be met. For aircraft with small tanks where the 200 gpm flow rate is not practical, it shall be possible to gravity refuel the aircraft in a maximum of 10 minutes from one refueling source using one hose.	Check each tank can be refueled at the required rate. At least one tank to be filled completely.
3.11.3 Ground Defueling. It shall possible to completely defuel the aircraft through a MIL-A-25896 adapter at a minimum rate of 200 gpm per adapter with a suction pressure at the adapter not in excess of 3 Psi. When the defueling adapter is not also used for refuelling, a positive means such as a check valve shall be used to prevent refueling through this adapter. The air-	Requires specific ground test.

TABLE 6 (Concluded)

Maintenance and Serviceability Requirements

REQUIREMENT	IMPACT ON TEST PLANNING
craft booster pumps may be used for defueling. In the event of a wheels-up landing it shall be possible to defuel the aircraft through the normal servicing adapters or by suction through accessible openings in each tank.	

TABLE 7

Ground Tests Required by MIL-F-38363[1] in Connection with

Aerial Refueling

TEST	COMMENT
Complete functional tests of all installed aerial refueling components. (4.5.6.2.1 (b))	
Demonstrate that the slipway door/ receptacle or probe and probe doors have the ability to extend and retract during hydraulic actuation at -65 deg. F temperatures and icing conditions. Fail safe provisions shall be demonstrated during the extreme temperature and icing condition tests. Actuation shall be accomplished under simulated flight air loads for the most adverse conditions. (4.5.6.2.1 (c))	Usually conducted by contractor during development. Record time of opening and hydraulic pressures. Will be checked during tests in Climatic Laboratory.
Perform compatibility tests to establish compatibility between tanker and receiver aircraft in respect to flow rates, pressures and surge pressures. (4.5.6.2.1 (g))	Tests include functional compatibility and leak tests and determination of maximum flow rate for acceptable surge pressures at shut off.

[1]Paragraph references are to MIL-F-38363B. The current version of this specification should be reviewed.

TABLE 8

COMPARISON OF TURBINE FUEL CHARACTERISTICS

Characteristics	JP-4	JP-8	JP-5	JET A	JET A-1	JET B
Density - at 60 degrees F						
Min/Max kg/l	0.751/0.802	0.775/0.840	0.788/0.845	0.775/0.840	0.775/0.840	0.751/0.802
lb/gal	6.27/ 6.69	6.47/ 7.01	6.58/ 7.05	6.46/7.01	6.46/7.01	6.27/6.69
Typical lb/gal	6.35	- - - -	- - - -		6.68	
Freezing Point Degrees F						
Max	-72	-58	-51	-40*	-50	-50*
Typical	Below -80	- - - -	- - - -	- - - -	-59	- - - -
Viscosity, Centistokes						
Max - 20 degrees C	- - - -	8.0	8.5	8.0	8.0	- - - -
Typical -30 degrees F	2.83	8.1	10.2	- - - -	7.74	- - - -
100 degrees F	1.00	1.50	1.77	- - - -	- - - -	- - - -
Flash Point Min degrees F	Subzero	100	140	100	100	- - - -
Heat of Combustion BTU/lb						
Min	18,400	18,400	18,300	18,400	18,400	18,400
Typical	18,727	18,433	18,498	- - - -	18,637	- - - -
BTU/gal						
Min	115,000	118,864	- - - -	- - - -	118,864	- - - -
Typical	118,916	- - - -	- - - -	- - - -	124,495	- - - -
Anti-Icing/Anti-Corrosion Inhibitor (%) min/max	0.10/0.15	0.10/0.15	0.10/0.15	Optional 0.10/0.15	Optional 0.10/0.15	Optional 0.10/0.15
Dielectric Constant @ 40 degrees F (See Figure 2)	2.090	- - - -	- - - -	- - - -	2.135	- - - -
Vapor Pressure (psi) at 100°F min/max	2.0/3.0	- - - -	- - - -	- - - -	- - - -	- - - -
Specification	MIL-T-5624	MIL-T-83133	MIL-T-5624	ASTMD/1655-79	ASTMD/1655-7	ASTMD/1655-79
NATO Designation	F-40	F-34	F-44	N/A	N/A	N/A

*The freeze points on the commercial fuels will vary.

TABLE 9A RECOMMENDED DATA PARAMETERS - GROUND TESTS

PARAMETERS	TESTS				
	FUEL QTY CAL	REFUEL & DEFUEL	FUEL TRANSFER	BOOST PUMP OFF	AERIAL REFUEL
Tank Quantities	X	X	X	X	X
Primary Pumps On/Off		X	X	X	
Deck Angle	X				
Secondary Pumps On/Off		X	X	X	
Engine inlet Fuel Press				X	
Fuel Temperature			X	X	
Xfer/Cross Feed[1] Manifold Press		X	X	X	
Aerial Ref Manfld[1] Pressure		X			X
Engine Fuel Flow			X	X	
Engine RPM			X	X	
Elapsed/IRIG Time		X	X	X	X
Event Marker		X	X	X	X

[1]When observing transients frequency response should be greater than 10Hz or a sample rate of 40 sec^{-1} to establish peak values.

TABLE 9B RECOMMENDED DATA PARAMETERS - FLIGHT TESTS

PARAMETERS	TESTS					
	Climb & Maneuvers	Level Flight	Fuel Jettison	Cross Feed & Transients	Aerial Ref Boom	Aerial Ref Probe
Individual tank fuel quantity (all tanks)	X	X	X	X	X	X
Primary fuel boost/ transfer pump on/off (all tanks)	X	X	X	X	X	X
Secondary fuel boost/ transfer pump on/off (all tanks)	X	X	X	X	X	X
Engine inlet fuel pressure(s)[1]	X	X	X	X	X	X
Fuel transfer/cross-feed manifold pressure (at least two locations)	X	X	X	X	X	X
Aerial refueling manifold pressure[1]					X	X
Fuel jettison valve open/ close (all locations)	X	X	X	X	X	X
Indicated or calibrated altitude	X	X	X	X	X	X
Indicated or calibrated airspeed	X	X	X	X	X	X
Individual fuel tank pressure (all tanks & vent sumps)	X	X	X	X	X	X

[1]When observing transients frequency response should be greater than 10Hz or sample rate of 40 sec^{-1}.

TABLE 9B RECOMMENDED DATA PARAMETERS - FLIGHT TESTS (Continued)

PARAMETERS	TESTS					
	Climb & Maneuvers	Level Flight	Fuel Jettison	Cross Feed & Transients	Aerial Ref Boom	Aerial Ref Probe
Vertical Velocity	X		X	X	X	X
3 axis accelerations at cg (Nx, Ny, Nz)	X	X	X	X	X	X
Pitch Angle	X	X	X	X	X	X
Angle of attack of fuselage reference line	X	X	X	X	X	X
Engine fuel flow(s)	X	X	X	X	X	X
Engine rpm (N_1, N_2, and N_3)	X	X	X	X	X	X
Elapsed time or IRIG time	X	X	X	X	X	X
Event Marker	X	X	X	X	X	X
Engine fuel inlet temperature	X	X	X	X	X	X
Return flow from heat exchangers	X	X	X	X	X	X
Inerting gas flow rate	X					

TABLE 9C RECOMMENDED DATA PARAMETERS - TANKER

Airspeed

Altitude

Outside air temperature

Boom/probe axial load

Boom/probe torsional load

Probe bending load (if relevant)

Tanker fuel flow (lbs/min)

Aerial Refueling pump(s) output pressure

Tanker fuel delivery pressure

Tanker fuel temperature

Hydraulic pump pressure driving refueling pumps

Boom position (azimuth, elevation, extension)

Boom control stick force

Boom Control surface positions

Telescope lever positions

Total fuel transferred (tanker)

Video tape recording or motion picture of boom/receptacle interface (boom pod and chase views)

Event marker

Elapsed time/IRIG time

Discretes (e.g. Contact, Disconnect, Ready)

ADDITIONAL PARAMETERS FOR KC-10:

Automatic Load Alleviation System (ALAS) state

Disconnect limit settings (delay, roll and pitch)

Boom nozzle vertical and lateral load

TABLE 9C RECOMMENDED DATA PARAMETERS - TANKER (Continued)

FOR KC-10 HOSEREEL OR OTHER HOSEREEL:

Boom nozzle fuel pressure

AR manifold fuel pressure

Boom Control Unit (BCU) discretes

Hose length

Fuel pressure at hose venturi

Fuel pressure in AR manifold

Hydraulic supply pressure

Hose reel response pressure

TABLE 10

Example of Maintenance Checklist Format (Incomplete List)

REQUIREMENT	COMMENT (Example Only
3.6.6.1 Fuel Boost Pumps. In fuel tanks of 1000 gallons or greater capacity pumps shall be removable without draining the tank. Boost pump leads shall have a disconnect.	Dash -2 shows compliance. Confirmed during removal of pump on tank.
3.6.6.3 Fuel Strainers. Shall be readily accessible and shall have sufficient clearance to permit easy removal of the cover and element. The filter or strainer shall be replaceable without draining the fuel from the system. Loss of the fuel in the assembly is acceptable.	Confirmed for all cases during normal maintenance.
3.7.1.3.2 Sump Drains. Operation of the drain shall remove all of the collected sediment and water with a minimum loss of fuel.	Confirmed for all tanks.
3.7.1.4 Access Doors. Each cell shall be provided with an access door of such size that the entire interior of the tank can be inspected and cleaned.	Confirmed for most doubtful case.

NOTE

Paragraph references are to MIL-F-38363B. The engineer should review the latest version of this Specification.

TABLE 11

TESTS WITH NOMINAL OPERATION OR SINGLE FAILURE

FLIGHT CONDITION	FUNCTION TO BE VERIFIED					
	FEED	TRANSFER	PRESSURIZATION	VENTING	CROSS FEED	TRANSIENTS
Normal climb MAX & MIL	Nominal & boost pump failure	Nominal & transfer pump failure	Nominal & any single failure	Nominal	Representative combinations	Nominal & boost pump failure
Fast idle power descent	-----	-----	Nominal & any single failure	-----	-----	-----
Zoom climb	-----	-----	-----	Nominal	-----	-----
Dive	-----	-----	Nominal & any single failure	-----	-----	-----
Sideslip, rolls, pushover, inverted flight	Nominal & boost pump failure	Nominal	-----	-----	-----	-----
Simulated weapon delivery	Nominal & boost pump failure	-----	-----	-----	-----	-----
High power level flight MAX & MIL	Nominal & boost pump failure	Nominal & transfer pump failure	Nominal	-----	Representative combinations	Nominal & boost pump failure
Cruise	Nominal & boost pump failure	Nominal & transfer pump failure	Nominal	-----	Representative combinations	Nominal & boost pump failure
Asymmetric Loading	-----	-----	-----	-----	Correction nominal & single failure	-----

NOTES

1. "Nominal" means with no subsystem/component failure.
2. Configurations with external tank should be tested
3. All maneuvers to be within 'dash 1' limits for the configuration.

TABLE 12

TESTS WITH DEGRADED FUEL SYSTEM OPERATION (DOUBLE FAILURE)

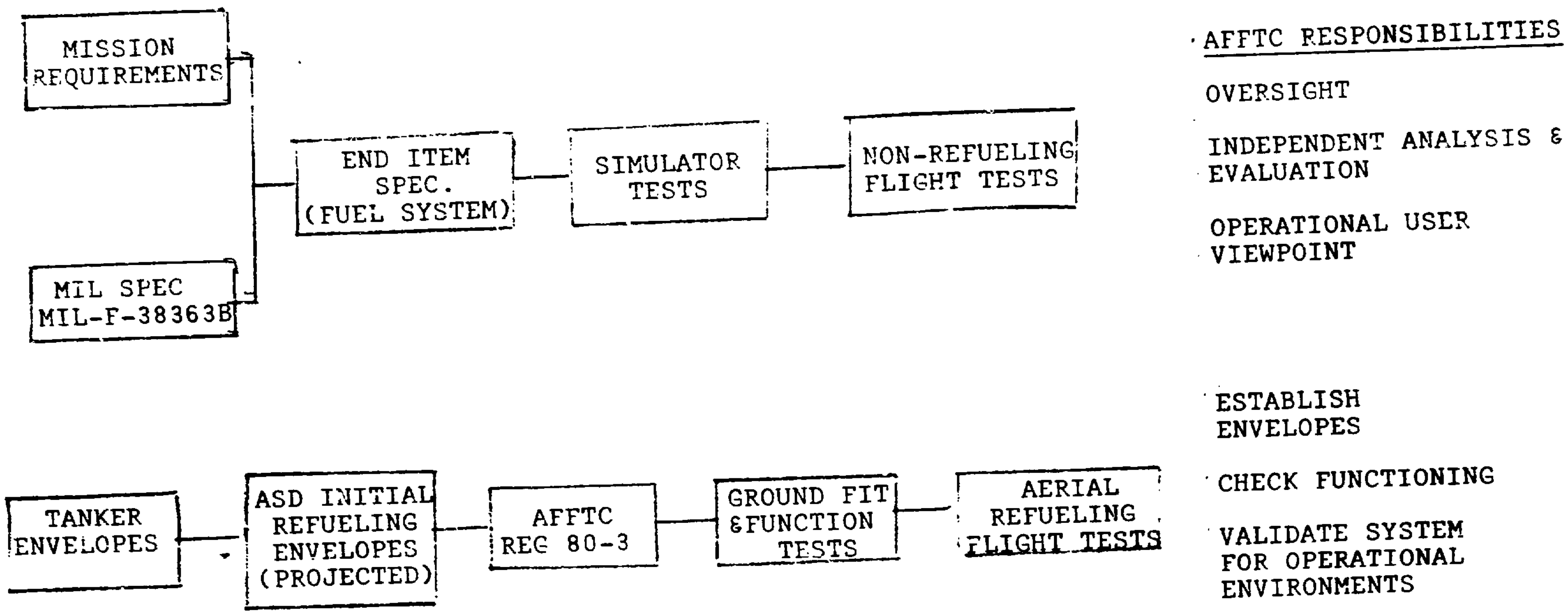
FUNCTION TO BE VERIFIED

FLIGHT CONDITION		FEED & TRANSFER	PRESSURIZATION	CROSS FEED	TRANSIENTS
NORMAL	MAX	X	X		Pump X Feed Throttle
	MIL	X	X		X
IDLE POWER DESCENT		X			
HIGH POWER LEVEL FLIGHT	MAX	X		X	X
	MIL	X		X	X
CRUISE		X		X	X

TABLE 13

Examples of Fuel Systems Failure Modes (F-15 Tests)

COMPONENT FAILED	BACK-UP MODE	PARAMETERS TO BE CHECKED
Main tank booster pump	1. Emergency boost pump	Engine inlet pressure at high flows
	2. Pressurization	Engine inlet pressure at high flows
	3. Gravity feed	Engine inlet pressure at high flows vs altitude, sideslip, etc.
Transfer pump	1. Pressurization	Adequate transfer at high powers
	2. Gravity feed	Transfer rate vs angle of attack
Automatic center of gravity control	Manual override	Clarity of procedures. Workload and degrees of attention.
Tank pressurization by bleed air	Ram air	Tank differential descent at low power and airspeed



NOTE ASD = Aeronautical System Division

FIGURE 1 POSITION OF AFFTC FLIGHT TEST IN DEVELOPMENT AND TEST PROCESS

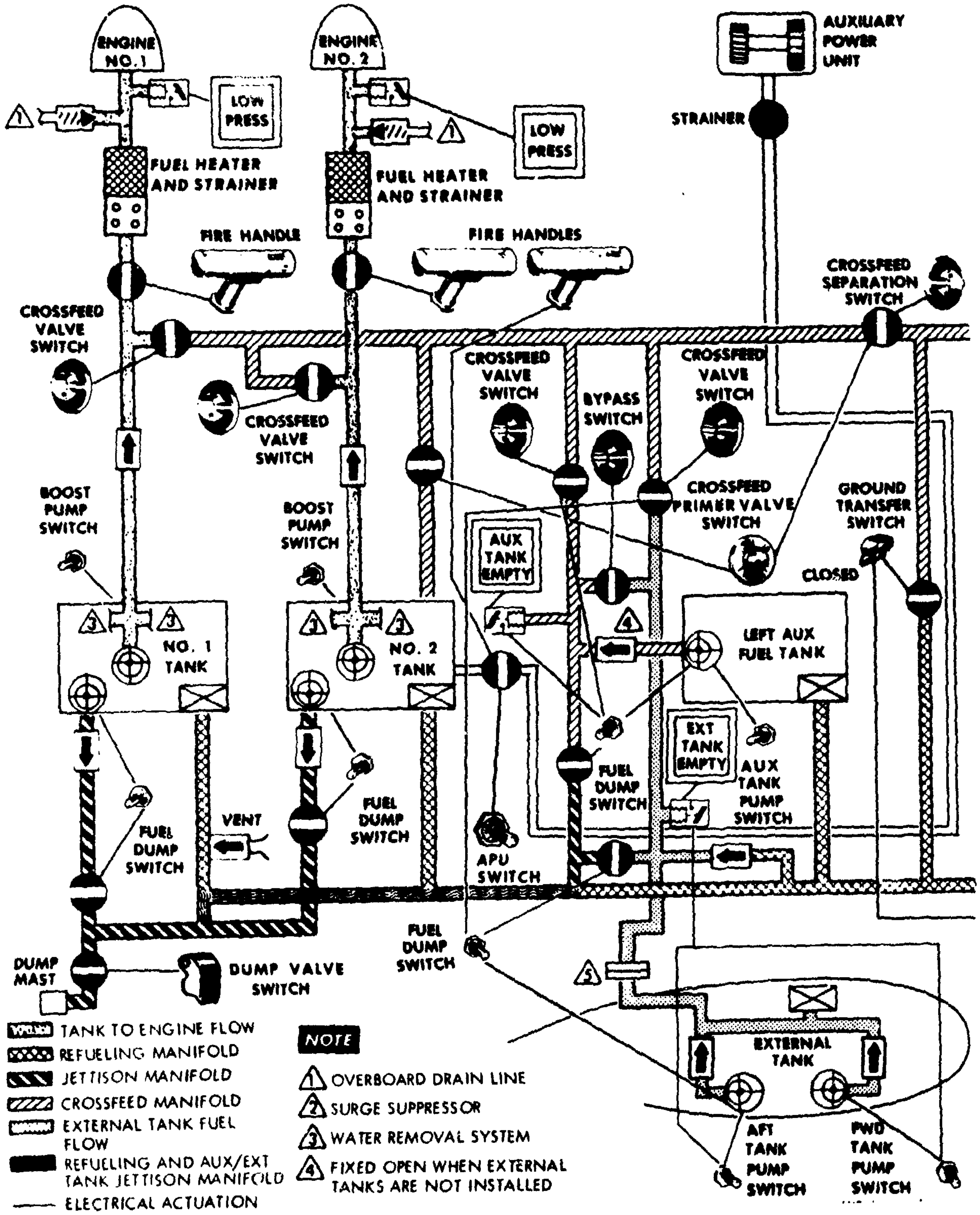


FIGURE 2 SCHEMATIC OF C-130H FUEL SYSTEM - PORT SIDE

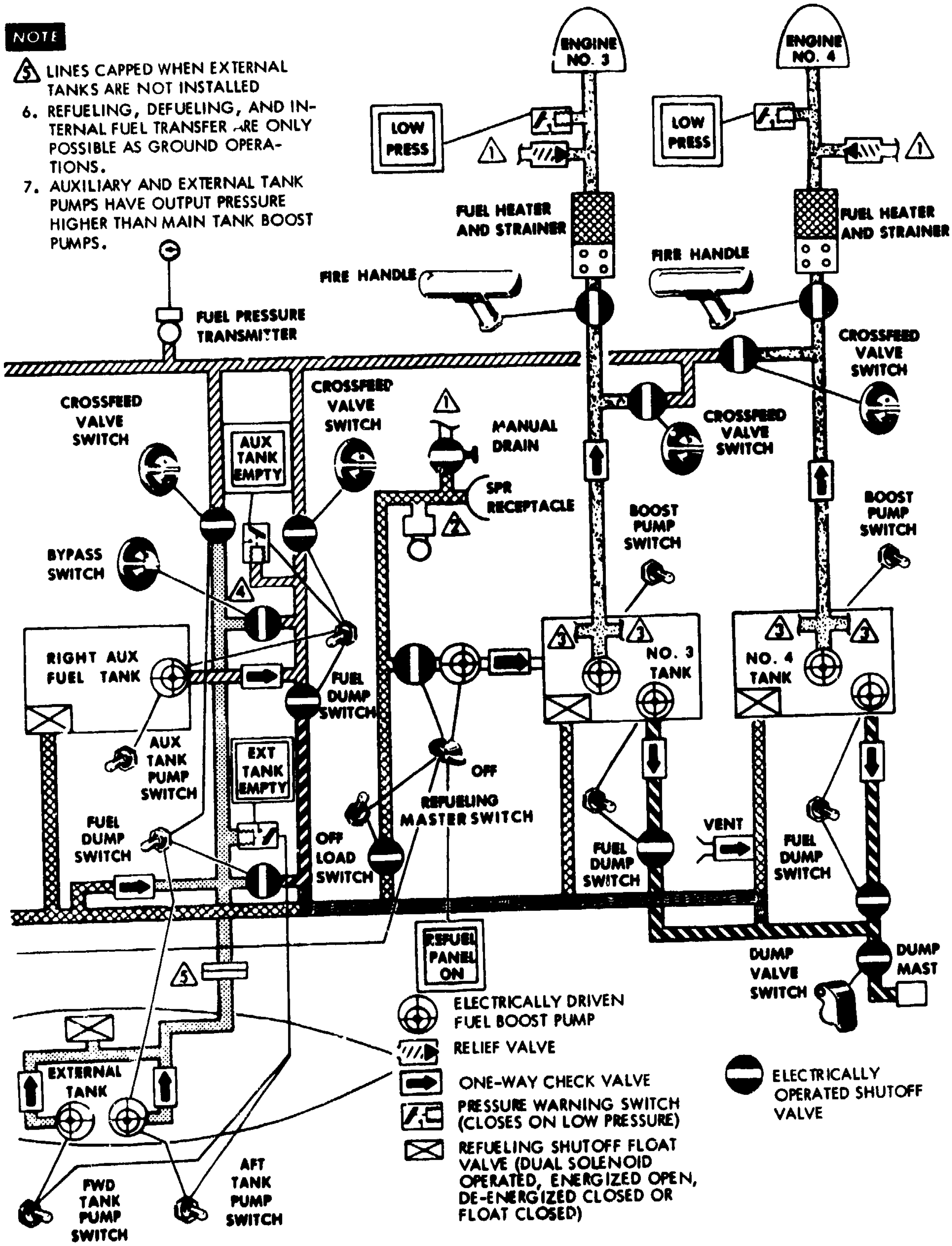
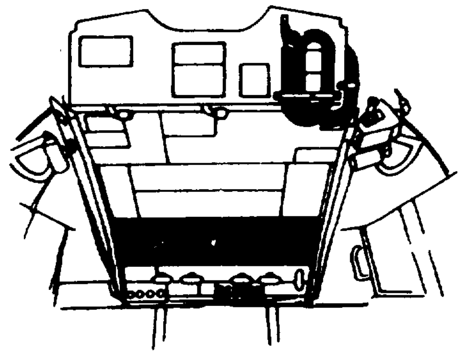
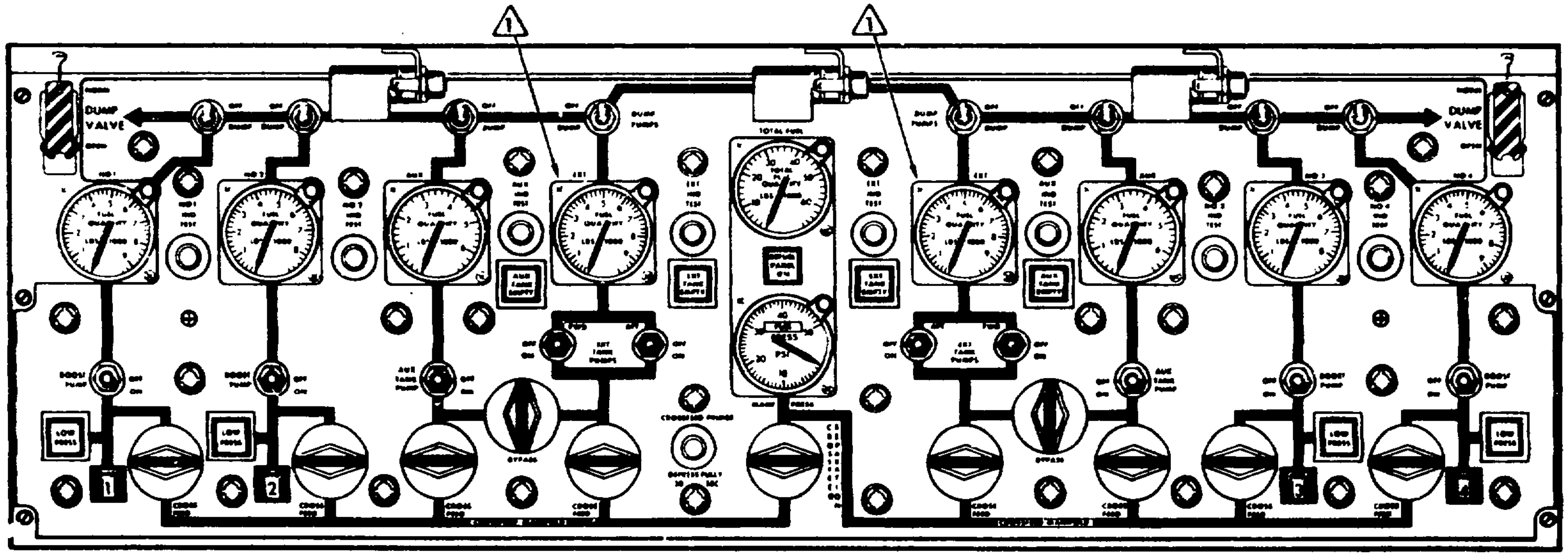


FIGURE 3 SCHEMATIC OF C-130H FUEL SYSTEM - STARBOARD SIDE



NOTE: FUEL CONTROL PANEL IS LOCATED OVERHEAD WITHIN REACH OF BOTH PILOTS AND OF THE NAVIGATOR.



NOTE

⚠1 INOPERATIVE WHEN EXTERNAL TANKS ARE NOT INSTALLED.

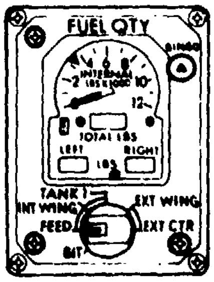
FIGURE 4 FUEL SYSTEM CONTROL PANEL - C-130H

FUEL QUANTITY DATA TABLE

JP-4 OR JP-8

TANK		USABLE FUEL			
	GALLONS	JP-4		JP-8	
		POUNDS AT 6.5 LB/GAL	POUNDS AT 6.3 LB/GAL	POUNDS AT 6.7 LB/GAL	
TANK 1 [1]		508	3300 ± 100	3200 ± 100	3400 ± 100
RIGHT ENG FEED TANK		234	1500 ± 100	1500 ± 100	1550 ± 100
LEFT ENG FEED TANK		184	1200 ± 100	1150 ± 100	1250 ± 100
INTERNAL WING TANKS	L	422	2750 ± 200	2650 ± 200	2800 ± 200
	R	422	2750 ± 200	2650 ± 200	2800 ± 200
TOTAL INTERNAL FUEL		1770	11,500 ± 450	11,150 ± 450	11,850 ± 450
EXTERNAL WING TANKS	L	610	3950 ± 250	3840 ± 250	4090 ± 250
	R	610	3950 ± 250	3840 ± 250	4090 ± 250
INTERNAL FUEL PLUS EXTERNAL WING TANKS		2990	19,400 ± 600	18,830 ± 600	20,030 ± 600
EXTERNAL ℄ TANK		610	3950 ± 250	3840 ± 250	4090 ± 250
INTERNAL FUEL PLUS EXTERNAL ℄ TANK		2380	15,450 ± 500	14,990 ± 500	15,940 ± 500
MAXIMUM FUEL LOAD TOTAL INTERNAL PLUS ALL EXTERNAL TANKS		3600	23,350 ± 650	22,670 ± 650	24,120 ± 650

[1] ON AIRCRAFT THRU BLOCK 9, SUBTRACT APPROXIMATELY 200 POUNDS FROM THE VALUES FOR TANK 1.



NOTES

- THE FUEL QUANTITIES, IN POUNDS, ARE ROUNDED OFF TO READABLE VALUES OF COUNTER PORTION OF THE FUEL QUANTITY INDICATOR; THEREFORE, THE ACTUAL GALLONS TIME 6.5, 6.3 OR 6.7 WILL NOT NECESSARILY AGREE WITH THE POUNDS COLUMN.
- FUEL WEIGHTS ARE BASED ON JP-8 AT 6.7 AND JP-4 AT 6.5 AND 6.3 POUNDS PER GALLON (DIFFERENCES ARE DUE TO MANUFACTURERS ALLOWABLE TOLERANCES) AND 65 DEGREES FAHRENHEIT.

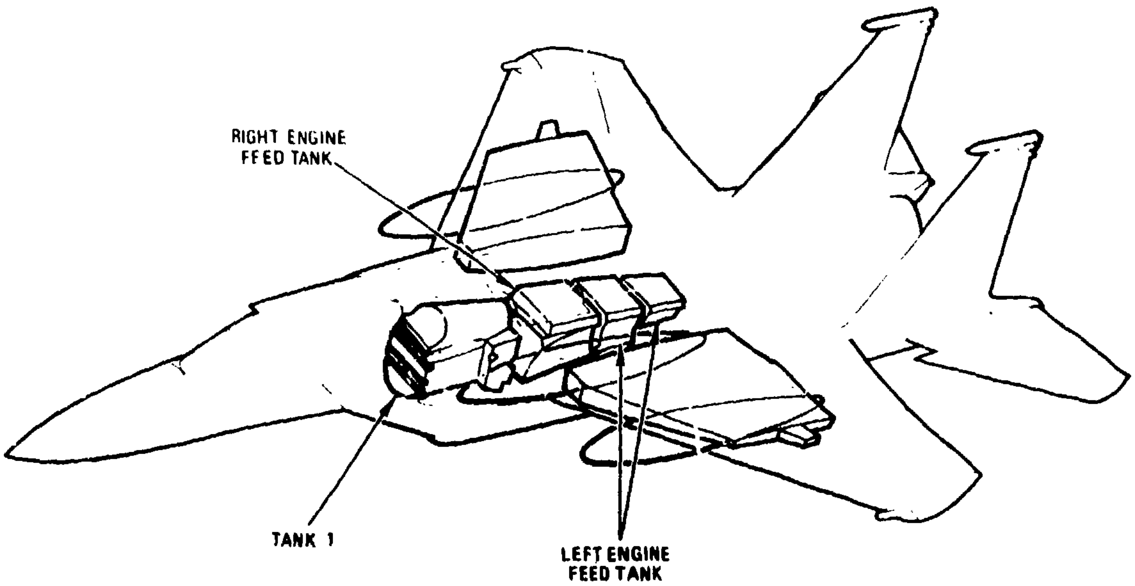


FIGURE 5 GAGING PRESENTATION AND TANK LAYOUT - F-15A

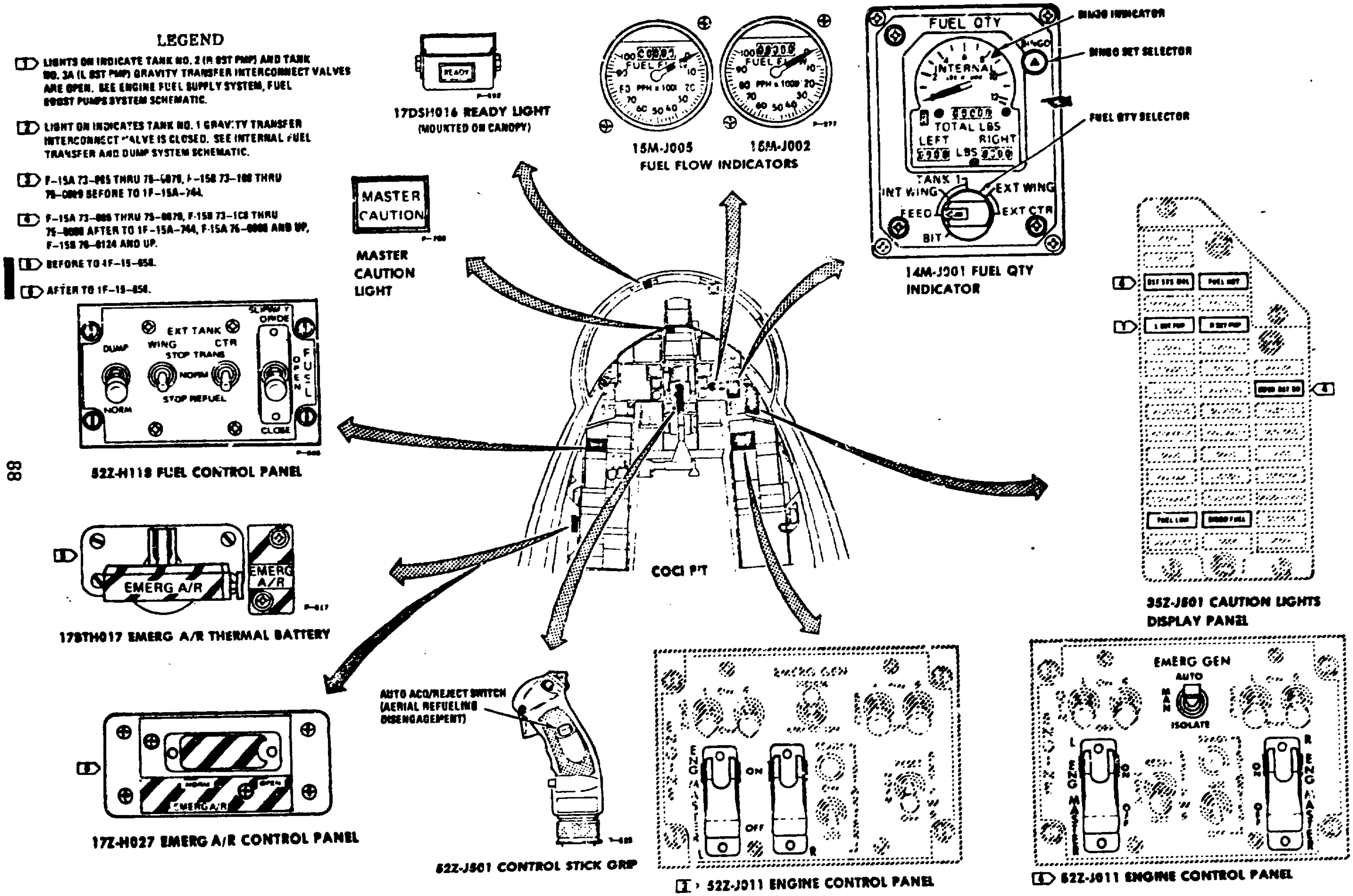


FIGURE 6 FUEL SYSTEM CONTROLS AND INDICATORS - F-15A

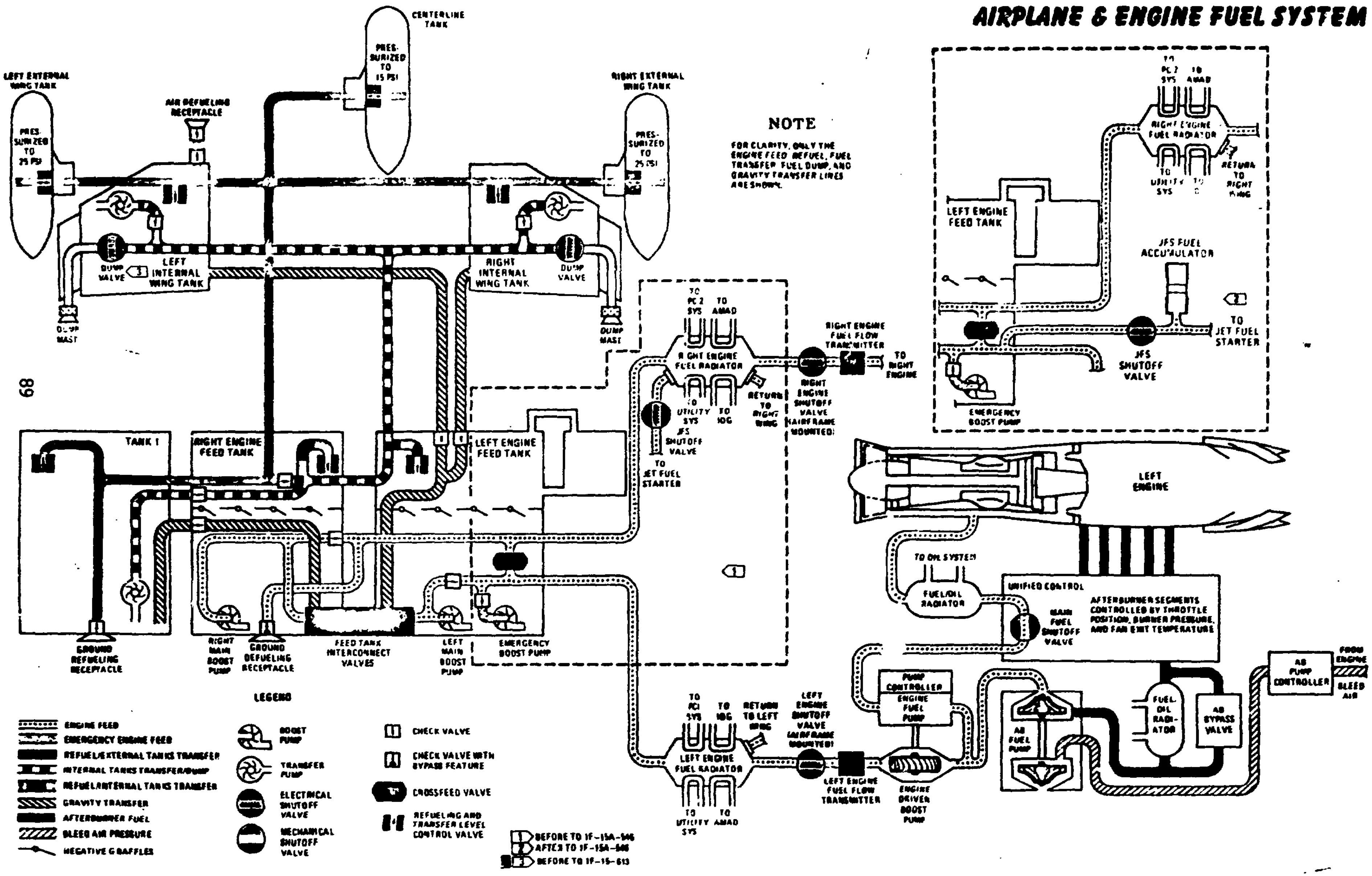
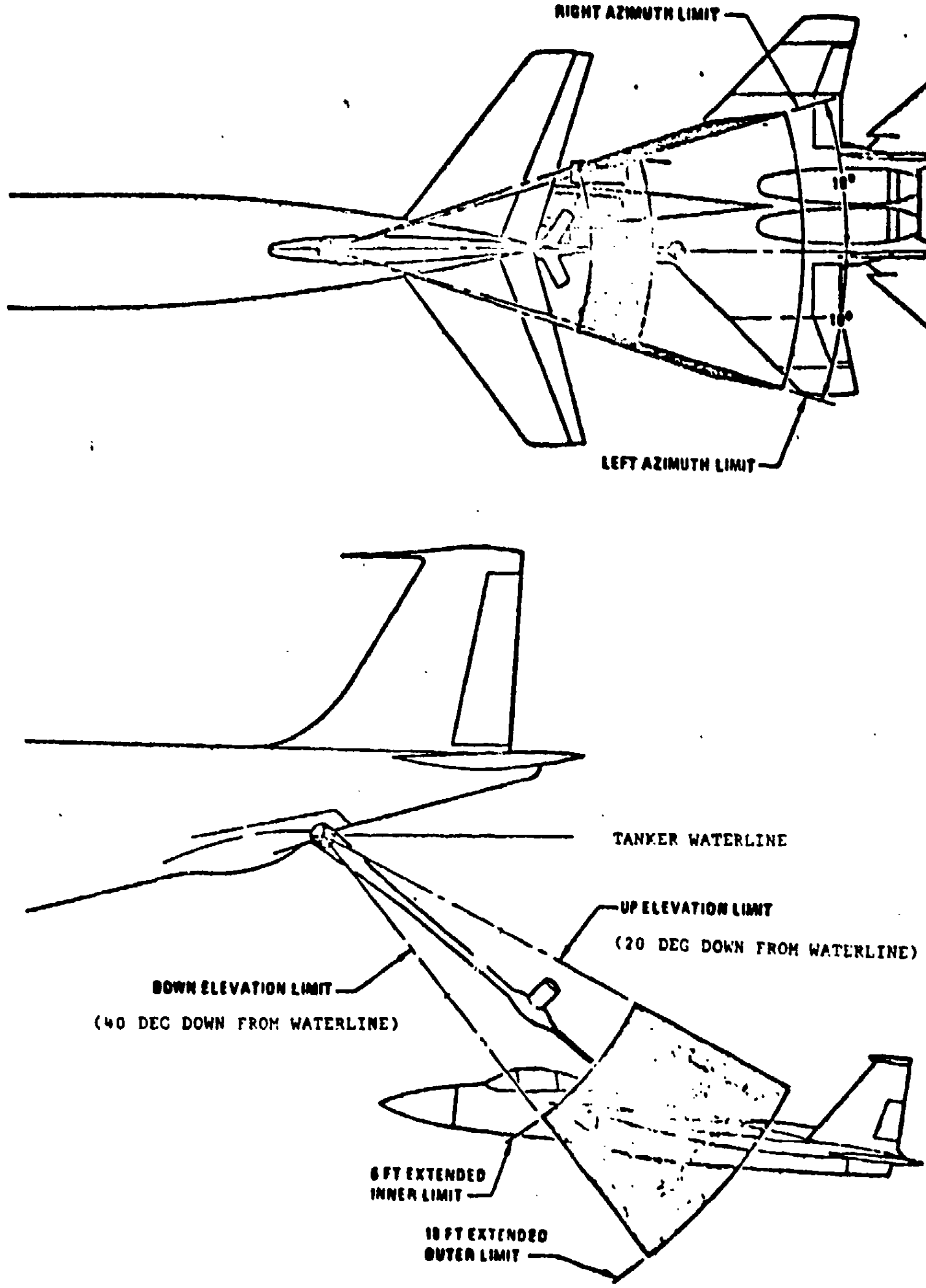


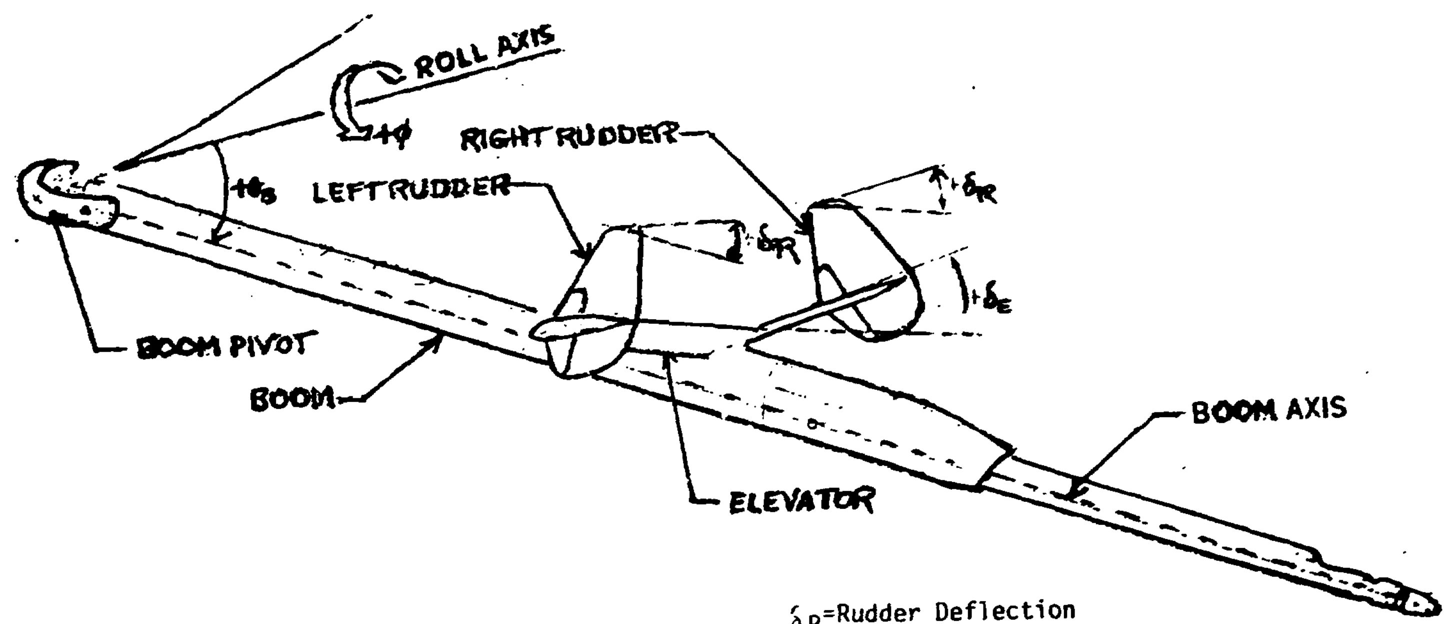
FIGURE 7 FUEL SYSTEM SCHEMATIC - F-15A



NOTE 1 ELEVATION IS MEASURED POSITIVE DOWNWARD FROM TANKER WATERLINE

NOTE 2 WITH FIGHTER RECEIVERS UPPER ELEVATION LIMIT IS OFTEN 25 DEG TO ENSURE BOOM/CANOPY CLEARANCE

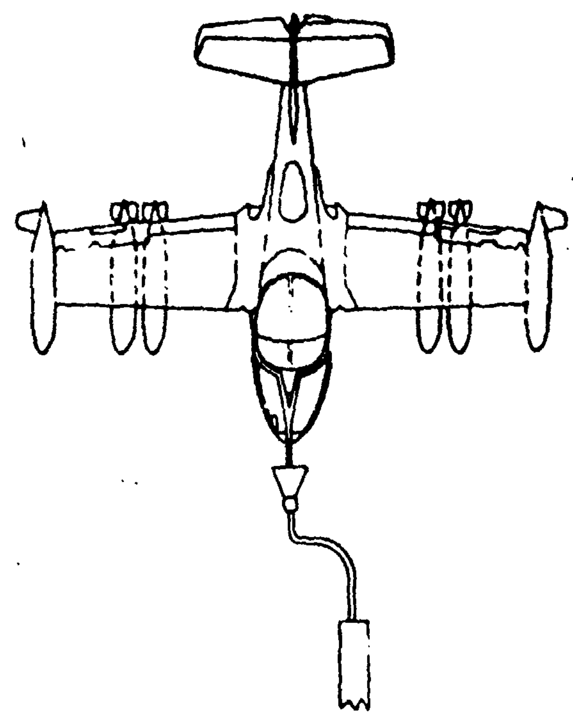
FIGURE 8 BOOM REFUELING INSTALLATION - KC-135



δ_R=Rudder Deflection
δ_E=Elevator Deflection
FRP=Fuselage Reference Plane
Ø=Boom Roll Angle
θ=Boom Pitch Angle

FIGURE 9 ADVANCED AERIAL REFUELING BOOM (KC-10)

PROBE AND DROGUE AIR REFUELING
AIR REFUELING THE A-37B



PRECONTACT POSITION

The boom will be trailed fully extended as follows:

DEGREES AZIMUTH	DEGREES ELEVATION
0	30°

FIGURE 10 REFUELING FROM KC-135 WITH BOOM TO DROGUE ADAPTOR KIT (PROBE DROGUE)

APPENDIX A

EXAMPLE OF TEST INFORMATION SHEET

AFFTC TEST INFORMATION SHEET (TIS) F-15 TEST PROGRAM	DATE 1974	PAGE 1 OF PAGES
TITLE OF TEST: Evaluation of Fuel Subsystem	VEHICLE TYPE: F-15	TIS NUMBER: 46
	EFFECTIVITY: 2, 8, & 9	REVISION: A

TEST TIME	TEST PERIOD	TESTING ACTIVITY	HAZARDOUS/UNUSUAL TEST
[X] PRIMARY	Feb 74 - Dec 74	AFFTC/DOVJ	No
[ ] CONCURRENT	LOCATION OF TEST: EAFB	TIS TYPE: [ ] PLAN [X] PROCEDURAL	SECURITY CLASSIFICATION: UNCLASSIFIED

1.0 REFERENCES:

1.1 F-15 Air Force Development Test and Evaluation Plan, AFFTC, July 1972.

1.2 F-15 Flight Manual, T.O. 1F-15A-1, (Preliminary).

1.3 McAir Report H277-1, Vol I, Books 1 and 2, F-15 Integrated Data System - Airborne Instrumentation System Description, 30 September 1971.

1.4 Military Specification, Fuel System, Aircraft, General Specification for, MIL-T-3836A (USAF), 23 December 1971.

1.5 Contractor DT&E TIS for Qualification of F-15A Fuel Subsystem, TIS No. CP089FF0001.01, 28 August 1973.

1.6 Prime Item Development Specification for F-15 Air Vehicle Fuel Subsystem, No. CP76301A328A089A McDonnell Douglas Corporation, 15 December 1969.

2.0 FUEL SUBSYSTEM DESCRIPTION WUC 46000

The fuel system is designed to operate automatically for all normal conditions. Emphasis has been placed on minimizing the pilot's task, redundancy to assure fuel availability, and protection against fire and explosion. Transfer of all internal and external fuel is automatic and functions without sensors. The system will provide fuel up to military power throughout the entire flight envelope with complete loss of normal electrical power. The aircraft has four fuselage fuel tanks and two wing tanks. The four fuselage tanks are designated tanks 1, 2, 3A and 3B. Tank 2 is the feed tank for the right engine and tanks 3A and 3B make the feed tank for the left engine. In addition, external, pylon mounted, droppable 600 gallon fuel tanks may be used. The fuel system also provides the capability for aerial refueling, overboard dumping of all fuel except that in the main feed tanks, a fire/explosion suppression system consisting of a grossly voided installation of reticulated foam, and pilot display of fuel quantity, low level warning and a "Bingo" fuel warning.

3.0 TEST OBJECTIVES:

ACTION	OFFICE OR POSITION/PHONE	SIGNATURE	DATE
PREPARE	AFFTC/DOEESF	[signature]	14 Feb 74
REVIEW	AFFTC/DOEES/DOVJE	[signature]	2-74
REVIEW	AFFTC/DOVJ/TACD-J	[signature]	
REVIEW	AFFTC/DOV	[signature]	4 Mar 74
APPROVE	AFFTC/DO	[signature]	6 MAR 1974

AFFTC FORM JAN 72 0-120

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AFFTC TEST INFORMATION SHEET (TIS) (F-15 TEST PROGRAM)	DATE 8 February 1976	PAGE 2 OF PAGES
TITLE OF TEST Evaluation of Fuel Subsystem	VEHICLE TYPE F-15	TIS NUMBER 46
	EFFECTIVITY 2, 8, & 9	REVISION A

TIS TYPE	LOCATION OF TEST	TESTING ACTIVITY	HAZARDOUS/UNUSUAL TEST
[ ] PLAN [X] PROCEDURAL	AFFTC	DOVJ	No

3.1 To demonstrate that the fuel subsystem operates without deficiencies during representative maneuvers throughout the operational envelope as specified in paragraphs 3.2.1.2.2 and 3.2.1.3.1 of reference 1.6. (reference 1.1, TIS No. 46, paragraphs 3.1)

3.2 To demonstrate satisfactory fuel subsystem operation in the most extreme air vehicle operating attitudes as specified in paragraph 3.2.1.2.3 of reference 1.6. (reference 1.1, TIS No. 46, paragraph 3.1)

3.3 To demonstrate that emergency operation of the fuel subsystem will be in accordance with paragraph 3.2.1.2.4 of reference 1.6. (reference 1.1, TIs No. 46, paragraph 3.1)

3.4 To demonstrate that either engine can be fed by either feed tank and that fuel flow to either engine can be deactivated without affecting fuel flow to the other engine, as required by paragraph 3.2.1.3 of reference 1.6. (reference 1.1, TIS No. 46, paragraph 3.1)

3.5 To demonstrate that fuel subsystem operation with one boost pump inoperative satisfies the requirements of reference 1.6, paragraph 3.2.1.3.4. (reference 1.1, TIS No. 46, paragraph 3.1)

3.6 To demonstrate that the low level and bingo warning system are consistent and meet the requirements of paragraph 3.2.1.8.1, reference 1.6. (reference 1.1, TIS No. 46, paragraph 3.5)

3.7 To demonstrate satisfactory operation of the fuel transfer system per paragraph 3.2.1.3.5 of reference 1.6. (reference 1.1, TIS No. 46, paragraph 3.1)

3.8 To define the quantity of fuel subsystem expansion space to satisfy the requirements of reference 1.6, paragraph 3.2.1.4.7. (reference 1.1, TIS No. 46, pragraph 3.1)

3.9 To demonstrate satisfactory operation of the fuel tank pressurization system to satisfy the requirements of reference 1.6, paragraph 3.2.1.5. (reference 1.1, TIS No. 46, paragraph 3.1)

3.10 To demonstrate that ground and inflight operation of the fuel vent system meet the requirements of reference 1.6, paragraph 3.2.1.7 and reference 1.4, paragraph 4.5.4. (reference 1.1, TIS No. 46, paragraph 3.1)

3.11 To demonstrate that the accuracy of the fuel quantity system satisfies the requirements of reference 1.6, paragraph 3.2.1.8. (reference 1.1, TIS No. 46, paragraph 3.5)

3.12 To demonstrate that ground pressure refueling satisfies the requirements of reference 1.6, paragraph 3.2.1.11. (reference 1.1, TIS No. 46, paragraph 3.2)

AFFTC FORM JUN 73 261 REPLACES AFFTC FORM 0- HICH WILL BE USED.

AFFTC TEST INFORMATION SHEET (TIS) (F-15 TEST PROGRAM)	DATE 8 February 1974	PAGE OF PAGES
TITLE OF TEST: Evaluation of Fuel Subsystem	VEHICLE TYPE: F-15	TIS NUMBER: 46
	EFFECTIVITY: 2, 8 & 9	REVISION: A

TIS TYPE	LOCATION OF TEST	TESTING ACTIVITY	HAZARDOUS/UNUSUAL TEST
[ ] PLAN [X] PROCEDURAL	AFFTC	DOVJ	No

3.13 To demonstrate that ground defueling satisfies the requirements of reference 1.6, paragraph 3.2.1.13. (reference 1.1, TIS No. 46, paragraph 3.2)

3.14 To demonstrate that fuel dump system performance satisfies the requirements of reference 1.6, paragraph 3.2.1.14 and reference 1.4, paragraph 4.5.7. (reference 1.1, TIS No. 46, paragraph 3.3)

3.15 To demonstrate that the aerial refueling system satisfies the requirements of reference 1.6, paragraph 3.2.1.9 and reference 1.4, paragraphs 4.5.6.2.1 and 4.5.6.2.2. (reference 1.1, TIS No. 46, paragraph 3.4)

4.0 TEST CONDITIONS/PROCEDURES: Specific tests are outlined in Table I. Numbers in the table indicate test item number. Paragraphs 1.0, 3.0, 4.0, and 11.0 require a total of 35 hours primary flight time. The remainder of the tests may be conducted in conjunction with other tests.

5.0 SUPPORT REQUIREMENTS:

5.1 Photo chase (F-4) will be required for all refueling flights. Use of the AFFTC KC-135 tanker with the instrumented boom is required for all aerial refueling flights.

5.2 F-15A production no. 8 (contractor operated), and no. 14 and TF-1 will be used for these tests. Instrumentation in no. 8 and TF-1 shall be in accordance with Table 2. Instrumentation in ship no. 14 consists of engine parameters primarily with limited fuel system parameters.

5.3 This TIS represents the test program as required by AFFTC. The test program is essentially parallel to the McDonnell Douglas fuel system qualification TIS No. CP089FF0001.01, dated 28 August 1973. It is anticipated that the contractor will perform the majority of the tests contained herein on F-8. In order for the AFFTC to meet the requirements of completing the tests outlined herein without duplication of testing, contractor data must be made available for AFFTC analysis and use in the final technical report. The F-15 SPO will arrange with the contractor to provide free access to and copies of all contractor data gathered under the above TIS.

AFFTC FORM JUN 73 261 REPLACES AFFTC FORM 0-128, JUN 73, WHICH WILL BE USED.

TIS ITEM	SPECIFICATION REQUIREMENTS REFERENCE SECTION	TEST DEFINITION										
1.0	3.2.1.2.3	Extreme Operating Attitude	ALTITUDE FT.	POWER SETTING	INTERNAL FUEL QUANTITY	MANEUVER VERTICAL CLIMB	VERTICAL DIVE	INVERTED FLIGHT (2)	360 ROLL	FULL RUDDER DEFLECTION STEADY SIDESLIP (3)		PUSHOVER THROUGH 0 G
										clean	power(4) approach	
			20-40K	Military (MIL)	75% - 100%	1.1	1.2	1.3*	1.4	1.5	1.6	1.7
					25% - 50%	1.8	1.9	1.10*	1.11	1.12	1.13	1.14
				A/B	75% - 100%	1.15	1.16	1.17*	1.18	1.19	-	1.20
					25% - 50%	1.21	1.22	1.23*	1.24	1.25	-	1.26
2.0	3.2.1.2.4	Emergency Operation	ECS Failure 2.1		Low, speed dive, idle power, 45-10K, ECS off (emergency ram air vent), speed brake extended.							
			Ram Air Inlet 2.2 Blocked		High speed dive, idle power, 45-20K ECS on (Ram air valve failure)							

REMARKS

Numbers 1.1 to 1.26 denote Test Point Number
(1) As obtainable with current engine configuration.
(2) Max nz 5.5g. Max AOA 25 units.
(3) Rudder deflection limits or yaw limits will be adhered to.
(4) Engine power as required.

Stabilize at each test condition.
* Negative g baffle is required. These tests will be performed on F-15A No. 9 or other suitable aircraft.

3.0	3.2.1.3	Feed and Transfer	TEST POINT NO.	ALTITUDE FT.	AIRSPEED KCAS		REMARKS
			3.1	5K	180		Demonstrate that either engine can be fed by either feed tank by selectively deactivating left and right boost pumps.
			3.2	10K	650		
			3.3	35K	650		
			3.4	45K	600		
			3.5	5K	500		Demonstrate that either engine can be deactivated without affecting fuel flow to the other engine by performing either left and right engine shutdowns and airstarts or afterburner cancellations to idle power.
			3.6	45K	500		
			3.7	5-40K	-		One main boost pump inoperative - Max power climb.
4.0	3.2.1.3.4	Main Boost Pumps Inoperative	TEST POINTS NO.	ALTITUDE FT.	MACH NO.	POWER SETTING	REMARKS
			4.1	5-30K	-	Mil	Maximum rate of climb, maximum obtainable fuel feed tank temperature at start-up (not to exceed 110°F). Reid vapor pressure measurement provided. Dual boost pump failure.
			4.2	5-10K	-	Maximum A/B	
			4.3	40K	0.9	Mil	Dual Boost Pump Failure.
			4.4	10K	0.9	Maximum A/B	
5.0	3.2.1.8.1	Low Level Warning System Operation	Performance Determined Concurrently With Other Tests in the Program.				
6.0	3.2.1.3.3	Transfer System Operation	Performance determined concurrently with tests of Item 1.0.				

7.0	3.2.1.4.7	Expansion Space		Ground Test. Refuel until normal shutoff. Deactivate shutoff. Add measured quantity of fuel using a low feed rate until expansion space is filled.
8.0	3.2.1.5	Pressurization System	TEST POINT NO.	REMARKS
			8.1	Ground test. Measure fuel efflux from fuel vents during normal refueling and refueling-to-overflow.
			8.2	Flight test. Selected maneuvers of TIS Items 1.0 and 2.0 will be monitored to satisfy these requirements.
			8.3	20 degree dive 40-20K with 3 external tanks, speed brake extended, idle power both engines.
			8.4	Idle, power descent 45 to 5K @ 250 kts.
9.0	3.2.1.7	Vent System Operation	9.1	Maximum A/B takeoff and climb to 50K.
			9.2	Ten ground engine starts with ECS on. Trap and measure fuel efflux from fuel vents.
10.0	3.2.1.8	Fuel Quantity Gaging		Performance determined concurrently with other tests in this program. Periodic pilot read fuel quantity values correlated with measured values.
11.0	3.2.1.9	Aerial Refueling	11.1 Hookups (1) (7) All hook-ups will be made at nominal boom angles of -30 degrees elevation and 0 degrees azimuth.	

Airspeed/Mach	Alt	Test No.
300 KCAS	30K	11.1.1
250 KCAS	35K	11.2.2
300 KCAS	35K	11.1.3
250 KCAS	25K	11.1.4
250 KCAS	25K	11.1.5
340 KCAS	25K	11.1.6

11.2 Disconnects (1) (2) (5) (6)

Airspeed/ Mach	Alt	Type Disconnect	Boom Extension	Boom Azimuth Angle	Boom Elevation Angle -20(1)	-25	-30	-35	-40(1)
300 KCAS	30K	Manual/ Auto	Minimum (Approx 404")	10 L	11.2.6	-	-	-	11.2.7
				5 L	-	11.2.2	-	11.2.3	-
				0	-	-	11.2.1	-	-
				5 R	-	11.2.4	-	11.2.5	-
				10 R	11.2.8	-	-	-	11.2.9
				15 R(1)	11.2.13	11.2.11	11.2.10	11.2.12	11.2.14
			Mid (Approx 478")	As Above - Test Point Nos. 11.2.15 to 11.2.33 apply.					

Both manual (pilot and boomer initiated and auto (full fuel tanks) disconnects will be performed at the flight condition of paragraph 11.D. Azimuth angle of 0 degrees and elevation angle of -30 degrees will be used.

Five forced disconnects will be made at 300 KCAS, 30,000 feet altitude. Disconnects will be made at nominal boom angles of -30 degrees elevation and 0 degrees azimuth. (These will not be performed by USAF until demonstrated by the contractor.)

11.3 Refueling Technique/Equipment Evaluation (3)

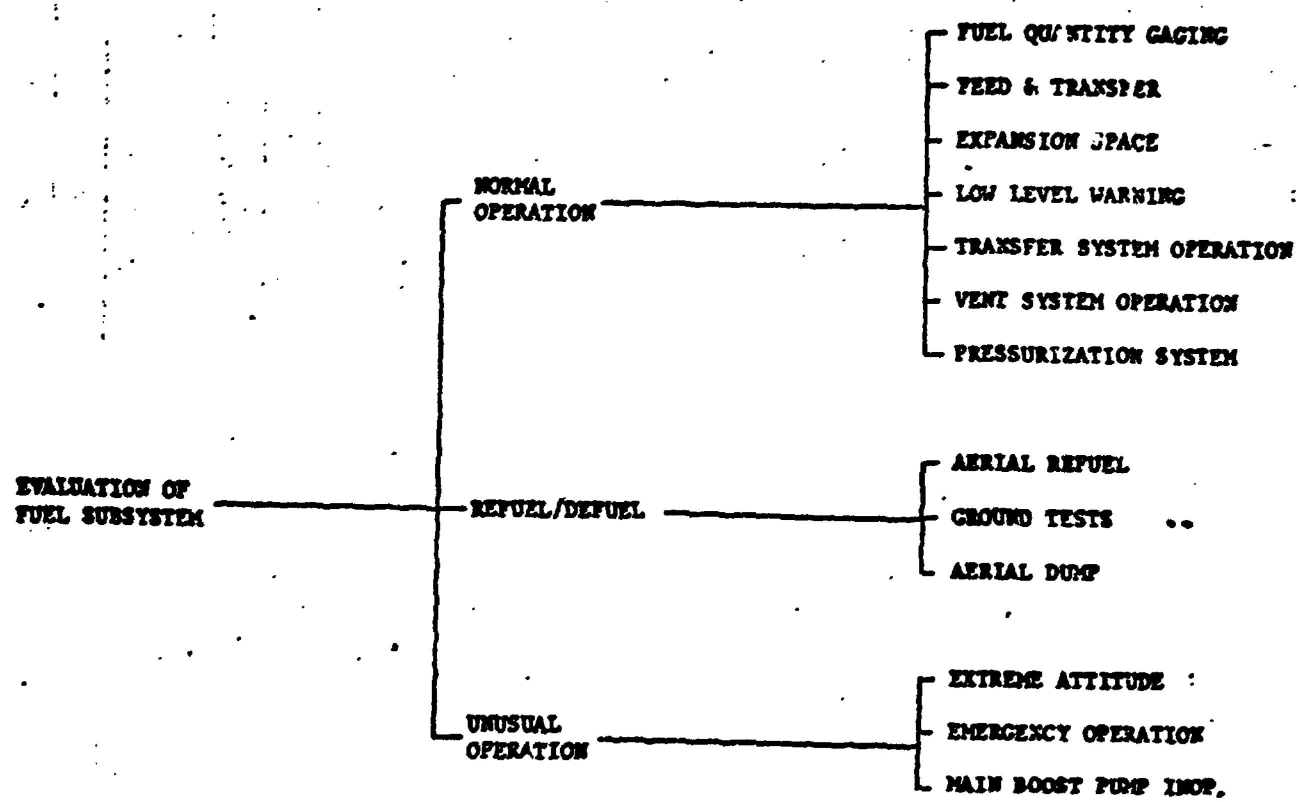
Test Point No.	Evaluation
11.3.1	Effects of Flap Extension of F-15/Tanker Compatibility
11.3.2	Use/Effectiveness of Speedbrake
11.3.3	Effects of Turbulence
11.3.4	Night Lighting Adequacy
11.3.5	Effects of Various F-15 Gross Weights

11.3.6	Top Off Capability
11.3.7	Towing Capability
11.3.8	Stiff Boom Hookup Capability
11.3.9	Effects of Various Combinations of Tanker Pumps
11.3.10	Effects of Various Tanker Gross Weights
11.3.11	Evaluation of Effectiveness of Cockpit Lighting and Controls
11.3.12	Evaluation of Override Capability

(1) Selected aerial refueling tests flown with three external fuel tanks.
(2) Target disconnect boom angles may be limited by proximity to aircraft/canopy. Test operational limit to be established by test.
(3) Evaluation performed concurrently with tests of Sections 11.1 and 11.2.
(4) Tanker to provide fuel flow rates, times, boom elevation, azimuth, extension, torsion, compression, tension, data as available. Number of operative pumps to be documented.
(5) A selected number of disconnects will be performed with tanker pumps "on" following transfer of fuel.
(6) Automatic disconnects to be performed by:
   (a) Exceeding boom limits.
   (b) Topping off receiver tanks.
   Manual disconnects to be initiated by both tanker boom operator and receiver pilot.
(7) Refuelings conducted following hookups as required. One refueling to be performed starting from 10% total internal plus external to establish refuel time to fill airplane.

12.0		**	Single engine refueling will be performed to determine best flight conditions. Initial conditions will be 18K ft, 225 KCAS. One engine will be at idle to simulate single engine operation.
13.0	3.2.1.11	Pressure Ground Refueling	Ground test. Four refueling documented. Basic airplane, centerline external tanks, two wing tanks, three external tanks. Start point 10% fuel in feed tanks.
14.0	3.2.1.13	Ground Defueling	Ground test. Three defuelings documented. Gravity boost pumps, suction method utilized.
15.0	3.2.1.14	Fuel Dump	

TEST POINT NO.	AIRSPEED KCAS	ALTITUDE FT.	REMARKS
15.1	300	5K	Dump wing and tank No. 1 fuel. Basic aircraft and three external tank configurations tested. Photo chase required.


EVALUATION OF
FUEL SUBSYSTEM
NORMAL
OPERATION
REFUEL/DEFUEL
UNUSUAL
OPERATION
FUEL QUANTITY GAGING
FEED & TRANSFER
EXPANSION SPACE
LOW LEVEL WARNING
TRANSFER SYSTEM OPERATION
VENT SYSTEM OPERATION
PRESSURIZATION SYSTEM
AERIAL REFUEL
GROUND TESTS
AERIAL DUMP
EXTREME ATTITUDE
EMERGENCY OPERATION
MAIN BOOST PUMP INOP.

APPENDIX B

EXAMPLES OF TEST PROJECT SAFETY REVIEW

F-16 REFUEL AND QUICK TURNAROUND

J.P.8 CLIMATIC TESTS

TEST PLAN SAFETY REVIEW

PROJECT TEST TITLE & JON 2185AO F-16 Hot Refuel And Quick Turnaround	PERFORMING AGENCY AFLC/IGY And F-16 JTF

REQUESTED BY (Typed Name and Rank)	SIGNATURE OF REQUESTING OFFICIAL	PHONE NUMBER	DATE
Pflueger, J. Capt		73108	27 Nov 78

I SAFETY REVIEW BOARD ACTION

	DATE	RISK LEVEL	CONTROL NUMBER
TEST PLAN SAFETY REVIEWED ON	27 Nov 78	See Remarks	78-81

	TEST PLAN REVIEWED. NO OPERATING HAZARD ANALYSIS REQUIRED.	X	TEST PLAN REVIEWED. OPERATING HAZARD ANALYSIS APPROVED. REK 4 Dec 78
X	TEST PLAN REVIEWED. FURTHER HAZARD ANALYSIS REQUIRED.		PRETEST HAZARDOUS TEST REPORT REQUIRED

SAFETY REVIEW BOARD MEMBERS

NAME, GRADE & TITLE	SIGNATURE	NAME, GRADE & TITLE	SIGNATURE
KELLOCK, R.E., LTC Chairman		SCHOB, W.J., LTC Operations Rep	
BAILEYS, R.J., CIV Weapons Safety		MILLER, C.H., CAPT Sys Engr Rep	
KILLEBREW, K.E., CAPT F-16 Pilot Rep	Kerry E. Killebrew	HILL, R.C., CAPT Hum Fact Engr Rep	

II BRIEF DESCRIPTION AND JUSTIFICATION OF TEST (Use additional sheet of plain bond paper if needed)

STARTING DATE	COMPLETION DATE
28 Nov 78	15 Dec 78

ADDITIONAL SRB MEMBER:

FORD, J.A., CIV
Unit Safety Rep

Per T.O. 00-25-172, a Systems Safety Engineering Analysis (SSEA) must be conducted prior to performing Combat Quick Turnaround (simultaneous refueling and munitions loading with the engine shut down) operations. This effort is also being used to develop Hot Refueling (refueling with engine operating) procedures.

Ground tests of F-16 refueling systems and airflow patterns with the engine operating will be conducted to assist in developing procedures for hot refueling and combat quick turnaround operations. If satisfactory procedures and preliminary technical data are developed, one or two hot refueling operations and approximately six quick turnarounds will be conducted.

These tests are being performed at the request of HQ USAF/LGY. AFLC/IGY is the designated OPR, and is being supported by the F-16 SPO and the F-16 JTF.

NOTE: This AFFTC Form 28 is being coordinated to approve the Hot Refueling and Quick Turnaround activities. Tech data developed for these tests will be approved by the Commanders appropriate representatives IAW AFFTCR 136-3. The special tests will be approved by a separate Form 28 after procedures have been approved by the members of this SRB.

III FINAL COORDINATION AND APPROVAL

TYPED NAME, GRADE AND TITLE	SIGNATURE	DATE	CONCUR YES	CONCUR NO	SUBJECT TO COMMENTS IN SEC IV
ROBERT E. ETTINGER, LtCol, USAF Director, F-16 JTF		4 Dec 78	✓		✓
WALTER J. SCHOB, JR, LtCol, USAF Dep Dir of Test Force Operations		29 Nov 78	✓		✓
WILLIAM T. TWINTING, Col, USAF Commander 6510 Test Wing		4 Dec 78	✓		✓
RAYMOND C. GRAZIER, Col, USAF AFFTC DIRECTOR OF SAFETY		6 DEC 78	✓		
[illegible] J. BURKLUND, Col, USAF AFFTC VICE COMMANDER Vice Commander		6 Dec 78	✓		

TEST ☒ APPROVED ☐ DISAPPROVED ☐ APPROVED SUBJECT TO MY REMARKS IN SECTION IV

TYPED NAME AND GRADE OF AFFTC COMMANDER	SIGNATURE OF AFFTC COMMANDER	DATE
PHILIP J. CONLEY, JR., Brig. Gen., USAF Commander		12-6-78

AFFTC FORM SEP 77 28 PREVIOUS EDITIONS ARE OBSOLETE PAGE 1 OF PAGES

1. A Safety Review Board (SRB) was conv ed in the Directorate of Safety conference room on 27 Nov 78. A list of attendees is attached.

2. An SSEA has been performed for several other tactical aircraft. These analyses usually include activities to define potential problem areas, establish a system, develop technical data, validate that data, and demonstrate (verify) the capability with actual exercises.

a. An SSEA team of AFLC, AFISC, and TAC personnel manages the effort. The host base provides the aircraft, support equipment, and personnel to participate in the tech data development and demonstration.

b. The F-16 effort will be conducted by a team which includes F-16 JTF support personnel, test engineering support, an F-16 pilot, and a production F-16 aircraft. The management team includes maintenance, POL, fire hazard, and weapons personnel, as well as F-16 SPO fuel systems and test and evaluation personnel.

c. AFLC/IGY will provide the team chief, who will function as Test Conductor for test activity. An F-16 systems test engineer will represent AFFTC on the management team. An F-16 crew chief, fulfilling the role of Refueling Supervisor, and an F-16 Munitions Loading Team will execute the activities, according to developed tech data, under the supervision of the Test Conductor. The AFFTC Commander is to retain overall safety responsibility.

3. HQ AFSC has waived the provisions of AFSCR 136-3 for this activity. To assure the Commander that adequate preliminary tech data has been developed, the following will occur.

a. The usual supervisory and staff personnel will observe the development and validation of the tech data.

b. The provisional data will be approved at the Commander's Review prior to conducting Hot Refueling or Quick Turnaround operations.

4. The goal of this effort is to conduct Hot Refueling and Combat Quick Turnaround operations. To develop the necessary technical data, analyses have determined that several special tests are required.

a. Since there is no capability to pre-check the high level fuel shutoff valves, a failure would result in a fuel spill through the tank vent system outlet. The quantity of fuel spilled (vented) before the supply could be shut off must be determined. The high level shutoff valve will be mechanically failed, and refueling will be continued until the Refueling Supervisors can terminate the fuel supply with a deadman switch (if a pantograph is used) or a signal to the pit/truck operator if a single-point hose is used. Spilled fuel will be caught in an appropriate bowser, and the quantity will be measured. Any continuing spill due to siphoning after supply shut off will also be noted.

b. Airflow patterns near the aircraft with the engine operating will be evaluated. A to-be-determined smoke source will be utilized to document airflow patterns with photography. Test conditions include still air and ambient wind conditions.

c. Previously reported fuel "misting" from the vent outlet will be evaluated during routine refuelings. Observers will use a mirror as a condensate collecting surface to determine if "misting" quantities are significant to the intended operation.

d. During tech data validation walk-through only, CBR clothing and equipment may be worn for some operations. (These evaluations are of a low priority, and will be performed only if reasonable to do so). The objective is to determine if participants can perform their functions with any reduced capacity presented by the CBR equipment.

5. The following comments apply to the special tests and tech data development activity discussions.

a. The SRB felt there were no test unique hazards associated with the validation walk-throughs, even if the participants were wearing CBR equipment.

b. The "misting" test observers will be aware of ignition source suppression procedures, and will conduct their activities under the supervision of the Refueling Supervisor.

c. The airflow evaluations could present toxic and/or corrosive hazards, depending on the smoke source to be used. Engine FOD and personnel injury to the person positioning the smoke source must also be addressed.

d. The tests to determine fuel spilled if a shutoff valve fails raised several questions related to potential hazards.

(1) Is it possible to rupture a fuel tank during these tests?

(2) Will the method used to fail the shutoff valve have any other effects on the fuel system operations? How will this failure be documented?

(3) Will the usual fuel bowser be able to contain the vented fuel at the rate it would be vented?

(4) Will participants be exposed to sprayed fuel?

6. The SRB identified the potential hazards listed on the attached OHAs. The incomplete OHAs will be used to assist in developing technical data. Final OHA will be reviewed and a risk level will be assigned at the AFFTC Form 28 approval briefing.

REMARKS FROM 4 DEC 78 SRB:

7. The SRB reconvened in the Directorate of Safety conference room on 4 Dec 78. A list of attendees is attached.

8. The following comments apply to paragraph 5 above.

a. The misting tests showed some misting by an FSD aircraft and no misting by a production aircraft, with or without the prototype ECP vent modification. Lower Explosive Limit of fuel vapor did not extend more than 24 inches from the vent.

b. The airflow tests were not conducted, as further analysis indicated they were unnecessary.

c. The open questions in paragraph 5d were closed by discussions with the F-16 SPO fuel engineer. Tests resulted in 3.8 gallons of fuel being vented.

d. The special tests and tech data development procedures were approved by a separate AFFTC Form 28, control number 78-91A.

9. General Comments

a. High level refueling shutoff valve failure considerations will require the use of a fuel bowser for hot refueling and quick turnaround operations.

b. Operations will not be conducted on aircraft with hot brakes.

c. A TAB VEE shelter area will be simulated with ropes and rubber traffic control cones for quick turnaround operations.

d. Two hot refuelings, one with JP-5 and the second with JP-4, will be conducted. Three quick turnaround operations will be conducted, with one of these conducted at night.

10. The SRB reviewed the final OHA and considered the tests to be Low Risk. Primary considerations were:

a. The F-100 engine does not constitute a significant ignition source while operating at idle, without pooled fuel directly beneath the engine inlet.

b. The addition of munitions operations on the wing opposite the refueling operation does not present a significant ignition source near the fuel vent.

c. Combining two operations, both of which are designed to be ignition-source-free, does not significantly increase the risk level from that of the separate operations.

27 Nov 78

ATTENDEES

NAME, RANK	FUNCTION	OFF SYM/PHONE
*Kellock, R.E., LTC	SRB Chairman	SES/73217
Worthington, J.A., 2Lt	F-16 SPO Test Coordinator	ASD/YPT/785-4789
Griffin, John, LTC	System Safety Engr - SSEA Tm	AFISC/SES/876-4703
Pfleeger, Jerry, Capt	A/C Systems FTE, F-16 JTF Directors Representative	73770
*Hill, R.C., Capt	Human Factors Engr	TEEEH/74107
Armstrong, G.C., GS-12	Human Factors Engr (Video)	TEEEH/73334
*Bailets, R.J., GS-12	Weapons Safety	74287
Cummings, G.L., Capt	F-16 JTF Weapons Officer	TEVFM/73468
Hicks, George M., SSgt	F-16 Crew Chief/ Fueling Supervisor	
Carnes, Larry E., SSgt	F-16 JTF Wpns LSC Member	73468
Gernand, Stan, CMSgt	F-16 JTF Wpns Support	73468
*Ford, James A.	F-16 JTF Unit Safety Officer	73102
Raney, John C., MSgt	12AF 388th TFW, Quality Control Fueling Supervisor	458-2024
Colburn, L.P., Civ	Supv, Sys Engr Br	73067
*Schob, W.J., LTC	JTF Operations	74230
Myers, L.P., Capt	Propulsion/Fuels Test Engr (SSEA Member)	72398
*Killebrew, K.E., Capt	F-16 JTF/Ops/Pilot	72795
*Miller, C.M., Capt	Systems Engr, SRB Rep	72756
Eckhart, John D., LTC	Sys Safety Engr, SSEA Team	AFLC/IGY/787-7131
DeHart, R.E. II	Safety Engr, SSEA Team	AFLC/IGY/787-713[illegible]
Turner, G. Brent	Load Stand	MATM/72947

* SRB Members

Attachment 1

F-16 Hot Refuel/Combat Quick Turn

4 Dec 78

NAME/RANK	FUNCTION	OFF/PHONE
*Kellock, R.E. LtCol	Chairman	SES/73217
Turner, G.B. MSgt	Load Stand	MATM/72947
Worthington, J.A. 2Lt	F-16 SPO Test Coordinator	ASD/YPDT/785-4789
Pfleeger, J.D. Capt	F-16 JTF Director's Rep	TEVF/350-3102
*Ford, J.A. GS-13	F-16 Unit Safety Officer	TEVF/350-3102
Andras, P.R. GS-12	F-16 SPO SSE (ASD/YPEC)	ASD/YPEC/785-4157
Klein, J.K.	F-16 Fuel Systems Engr	ASD/YPEJ/785-3847
Adams, Arlie E.	SSEA Asst Chairman	AFLC/IGYW/787-7872
Newbern, R.G.	Explosive Safety Engr	AFSC/IGFG/858-2306
*Bailets, R.J.	Weapons Safety	AFFTC/SEW/350-4287
Cummings, G.L. Capt	F-16 JTF Wpn Officer	TEVF/350-3468
Griffin, J. LTCol	System Safety	AFISC/SESO/876-4703
Wiles, J.A.	System Safety Engr	AFFTC/SES/73217

*SRB Members

Atch 2

OPERATING HAZARD ANALYSIS

TEST SERIES: F-16 Combat Quick Turnaround/Hot Refuel

HAZARD/UNDESIRED EVENT	CAUSE	EFFECT	HAZARD CATEGORY	CORRECTIVE ACTION/MINIMIZING PROCEDURES	REMARKS
Fire/Explosion	Spilled or vented fuel and ignition source	Damage to/or loss or A/C and personnel injury.	I	1. Spilled fuel will be washed down immediately. 2. Additional fire protection shall be provided by on-site standby fire truck. 3. Container of adequate size will be placed under left wing vent port to catch any fuel venting as a result of failed shutoff valve. 4. Transmissions from UHF or VHF radio shall be limited to emergency situations. 5. Ground interphone communications shall be maintained with the pilot during the entire refueling operation and will not be disconnected during refueling operation. 6. Only inert munitions will be used for these tests. Pylons will not be armed. 7. A minimum of two 50 pound capacity carbon dioxide or equivalent fire extinguisher will be used. One extinguisher will be near the fuel truck or hydrant used for replenishing and the other will be in the immediate vicinity of servicing connection point. 8. Applicable F-16 hot refueling checklists, as finalized by the SSEA and approved by appropriate AFFTC personnel to satisfy the intent of AFFTCR 136-3, will be followed. 9. Munitions load crews will not work under the left wing during refueling. 10. Hot refueling emergency procedures cover fire on aircraft, fire in refueling area, fuel spill, and fuel venting into bowser. Quick turnaround operations do not require additional emergency procedures.	4. Standard Procedure 5. Pilot not in cockpit, no headsets for quick turn. 7. Standard Procedure

AFFTC FORM 28A

OPERATING HAZARD ANALYSIS

TEST SERIES
F-16 Combat Quick Turnaround

HAZARD/UNDESIRED EVENT	CAUSE	EFFECT	HAZARD CATEGORY	CORRECTIVE ACTION/MINIMIZING PROCEDURES	REMARKS
Collision of Support Equipment with aircraft	Movement of equipment in vicinity of aircraft or misuse of aircraft systems.	Possible damage to aircraft and personnel injury.	II	1. All movement of equipment in immediate vicinity of aircraft will be accomplished under supervision of the replenishing team chief to preclude possible damage to aircraft and injury to personnel. 2. Insure all stands and equipment are removed which might cause damage when the aircraft shock struts compress or extend due to fuel load. 3. Preliminary F-16 T.O 1F-16A-33-1-4, Non-nuclear Integrated Combat Turnaround procedures, as finalized by the SSEA and approved by appropriate AFFTC personnel to satisfy the intent of AFFTCR 136-3, will be followed. 4. T.O. procedures establish to work one side of the aircraft with one crew.	2. Walk thrus show negligible settling.

AFFTC FORM APR 77 28A

TEST PROJECT SAFETY REVIEW

I. SAFETY REVIEW REQUEST

PROJECT TEST TITLE & JON: JP-8 Climatic Tests 921AJT, 921AJV, 921AJS	PERFORMING AGENCY: 6510 TW/TEOB, (OV-10A, A-37B); TEEES (F-5E)		
PROJECT MANAGER (Typed Name & Grade): Allan T. Webb, GS-12	SIGNATURE: Allan T. Webb	PHONE NUMBER: 2756/4693	DATE: 31 May 79
UNIT SSO (Typed Name & Grade): R. E. Black, Capt	SIGNATURE: Robert E Black	PHONE NUMBER:	DATE:

II. SAFETY REVIEW BOARD ACTION

TEST STARTING DATE	TEST COMPLETION DATE	RISK LEVEL	CONTROL NUMBER
1 June 79	13 July 79	Low Risk	79-35

	TEST PLAN REVIEWED. NO OPERATING HAZARD ANALYSIS REQUIRED.	X	TEST PLAN REVIEWED. OPERATING HAZARD ANALYSIS APPROVED.
	TEST PLAN REVIEWED. FURTHER HAZARD ANALYSIS REQUIRED.		PRESTO HAZARDOUS TEST REPORT REQUIRED.

III. SAFETY REVIEW BOARD MEMBERS

NAME, GRADE & TITLE	SIGNATURE	NAME, GRADE & TITLE	SIGNATURE
Saxon, V.P., Major Chairman	V. P. Saxon		
FOR Klein, H., Major OPS Representative	Robert E Black		
McKinney, J.S., Lt Col Engineering Rep	J S McKinney		
Tucker, R.C., Civ Systems Engineer	Robert C Tucker		

IV. BRIEF DESCRIPTION AND JUSTIFICATION OF TEST
(Use additional sheet of plain bond paper if needed)

Requesting Officials

Michael Dauth, Capt (OV-10A)

Royce Grones, Capt (A-37B)

Allan Webb, GS-12 (F-5E)

The purpose of this limited test program is to determine suitability of JP-8 fuel for use at low ambient temperatures. The test aircraft for this program will be the OV-10A, A-37B, and F-5E.

JP-8 fuel conversion efforts are established by Hq USAF Program Management Directive "The Conversion of Air Force in Europe Facilities and Land Based Jet Aircraft to Use JP-8 (NATO F-34)"; dated 14 Feb 78. The San Antonio Air Logistics Center (SA-ALC), as system manager for the OV-10A, A-37B, and F-5E, requested the AFFTC to evaluate JP-8 fuel for normal use in these aircraft. These Climatic Laboratory tests are a portion of the overall JP-8 fuel qualification program.

Publications Reviewed

Category II Climatic Evaluations of F-5A Aircraft ASD-TR-65-13, dated September 1965
F-111E/F/M32A-60A Cold Temperature Starting Evaluation With JP-8 Fuel in the McKinley Climatic Laboratory SM-ALC-TR-78-179 dated November 1978.

V. FINAL COORDINATION AND APPROVAL

COORDINATING OFFICIAL: TYPED NAME, GRADE AND TITLE	SIGNATURE	DATE	CONCUR YES	CONCUR NO	COMMENTS ADDED YES	COMMENTS ADDED NO
THOMAS J. LE BEAU JR Chief, Bomber Transport Branch	Thomas J. Le Beau Jr	4 Jun 79	✓			
JAMES H. MANLY, Lt Col, USAF Commander 6512 TESTS	[illegible]	4 Jun 79	✓			
6510 TESTW/TEE	[illegible], GS	4 Jun 79				
WILLIAM T. TWINTING, Col, USAF 6510 TEST WING COMMANDER	William T. Twinting	6 Jun 79	✓			✓
RAYMOND C. GRAZIER, Col, USAF AFFTC DIRECTOR OF SAFETY	Raymond C. Grazier	6 JUN 79	✓			✓
J. S. [illegible], Colonel, USAF Vice Commander	John S. [illegible]	7 JUN 1979	✓			✓

TEST ✓ APPROVED ☐ DISAPPROVED ☐ APPROVED SUBJECT TO MY REMARKS IN SECTION VI

TYPED NAME AND GRADE OF AFFTC COMMANDER	SIGNATURE OF AFFTC COMMANDER	DATE
PHILIP J. CONLEY, JR., Maj Gen, USAF Commander	[illegible]	7 JUN 1979

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VI. REMARKS

AFFTC Form 28's Reviewed

F-15 Systems AFDT&E (Climatic Lab) 1 May 1974

E-3A Climatic Laboratory Tests 14 February 1977

F-16 FSD Climatic Test Program 3 February 1978

1. The Safety Review Board was held at 1300 hours on 25 May 79 in the Safety Conference Room. In addition to the Board members listed in Section III, the following individuals were present:

Major W. Hohweisner	TEOF/USSO	3240
Capt R.E. Black	TEOB/USSO	3410
Capt J.R. Anderson	TEEES/A-37 Proj Eng	2756
Capt M.A. Dauth	TEOB/OV-10 Proj Pilot	3410
Capt R. Grones	TEOB/A-37 Proj Pilot	3410
Mr. R. Stambovsky	TEEES/OV-10 Proj Eng	2756
Mr. A.T. Webb	TEEES/F-5E Proj Eng	2756

2. Test Objectives: The primary objective of this test is to determine the minimum temperature for reliable engine start and operation for the F-5E, A-37 and OV-10 using JP-4 and JP-8 fuel. An ancillary test will be the cold temperature evaluation of the MA-1A start cart using JP-8 fuel.

3. General Procedures: These tests will be conducted in the Climatic Laboratory at Eglin AFB, Florida. All three aircraft will be positioned in the hangar and be operated sequentially. Test conditions will involve dry, cold weather tests down to -50°F using build-up techniques by gradually decreasing temperatures. The tests will include engine starts and engine runs up to maximum power using JP-8 and JP-4 fuel with engines trimmed to both JP-4 and JP-8 settings. An approximate 50/50 mixture of JP-4 and JP-8 fuel may also be tested if funding and time are available.

All operations in the Climatic Laboratory will follow standard laboratory procedures. Prior to conducting these tests another safety review will be held at Eglin AFB.

4. Specific Procedures: a. Test engine operations will be suspended whenever any fuel leaks or spills are detected until cleared by appropriate laboratory and Eglin Fire Department personnel.

b. Personnel on the floor of the laboratory will be kept to the minimum practical for the test conduct.

c. All engine operations will be conducted by crewmembers who are fully qualified to do so.

d. All cockpit engine instrument are required to be operative for engine operation.

e. T.O. restrictions and procedures will be followed where specified. If no specific restrictions exist, the test will follow ALC directions.

5. The SRB reviewed the attached OHA and the board considered these tests to be Low Risk due to the extensive experience that Climatic Laboratory personnel have in these types of tests and the low probability of occurrence of the specific hazards.

PAGE OF PAGES

OPERATING HAZARD ANALYSIS (OHA)

PAGE 1 OF 2 PAGES

TEST SERIES	PREPARED BY (Name and Title)	SIGNATURE	REVIEWED BY (Name and Title)	SIGNATURE
JP-8 Climatic Tests	ALLAN T. WEBB, Project Manager	Allan T. Webb	ROBERT C. TUCKER Ch., Aero-Mechanical Sect.	Robert C Tucker

HAZARD	CAUSE	EFFECT	HAZARD CATEGORY MIL-STD-882A	CORRECTIVE ACTION/MINIMIZING PROCEDURES	REMARKS
Fuel leaks spills with ignition source		Possible fire damage to aircraft and injury to personnel	I	The laboratory standard fire prevention/protection procedures (Ref. Climatic Laboratory OI 92-1) will be adhered to. These include ducting exhaust outside the laboratory, having a Fire Guard on duty during testing with laboratory approved fire extinguishers, and having a fire truck posted outside the quick opening door as required. Test briefings will include areas to watch for leakage. Approved laboratory procedures will be used for fueling and defueling.	
Aircraft falling off pedestals	Restraint failure.	Aircraft damage and/or injury to personnel.	II	The landing gear will be locked in the "DOWN" position, and the aircraft will be secured by laboratory approved restraints. Restraints will be designed to withstand maximum power on both engines plus a safety factor.	
Engine ingestion or propeller impact of foreign objects or personnel.	Complex equipment setup, duct inspections, ice accumulations in duct.	Engine/propeller damage and/or injury or death to personnel.	I	Inlets and propellers as well as floors will be inspected for ice and FOD prior to all engine runs. Personnel on the laboratory floor will be controlled by the test conductor, and will be restricted to safe areas. Test conductor will insure proper briefings and proper positioning of personnel prior to engine start and during engine operations.	
Toxic atmosphere	Venting or leaking of fuel or leakage of exhaust fumes	Personnel injury due to inhalation of fuel fumes or carbon monoxide.	II	Air purity will be monitored by Eglin AFB personnel in accordance with standard laboratory procedures. Air circulation in the laboratory minimizes accumulation of fumes.	

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OPERATING HAZARD ANALYSIS (OHA)

PAGE 2 OF 2 PAGES

TEST SERIES	PREPARED BY (Name and Title)	SIGNATURE	REVIEWED BY (Name and Title)	SIGNATURE
JP-8 Climatic Tests	ALLEN T. WEBB Project Manager	Allen T. Webb	ROBERT C. TUCKER - Ch., Aero-Mechanical Sect	Robert C. Tucker

HAZARD	CAUSE	EFFECT	HAZARD CATEGORY MIL-STD-882A	CORRECTIVE ACTION/MINIMIZING PROCEDURES	REMARKS
Environmental extremes	Low temperature test condition	Personnel injury	II	Approved protective clothing will be used and standard laboratory procedures adhered to during testing. All test personnel will be briefed on cold temperature injury prevention prior to start of testing. Test temperature progression will be gradual in nature. The buddy system will be used and personnel will watch each other for signs of frostbite. Test conductor and/or lab personnel will monitor length of exposure of personnel on floor. Prescribed routes will be marked and hazards will be highlighted. Personnel movement in the laboratory will be controlled by the Test Conductor. No freezing rain tests are planned.	

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APPENDIX C

EXAMPLES OF OPERATING PROCEDURES FOR HOT REFUELING AND WITH ALTERNATE FUELS

ALTERNATE FUEL

The aircraft may be operated on JP-8, NATO F-34, NATO F-35 or commercial JET A-1 and JET B. Except for possible icing and corrosion inhibitor differences, JP-8, F-34, F-35 and JET A-1 are equivalent and the same operating limitations apply. Except for the freeze point and possible icing and corrosion inhibitor differences, JET B and JP-4 are equivalent and the same operating limitations apply.

The engines should be trimmed for the fuel being used. Starts with temperature below −20°C with alternate fuel may produce more smoke and require a longer time for engine light-off. Ground starts should not be made with fuel temperature below −40°C.

The following restrictions apply when 25% or more of a second fuel is added. Afterburner operation with JP-8 while trimmed for JP-4 should be limited to mid range and below to prevent afterburner blowout and possible damage. Operation with JP-4 while trimmed for JP-8 is limited to 2.2 Mach or below to prevent compressor damage.

Due to alternate fuel freeze points, fuel in external tanks may not transfer after sustained operation (5 minutes or longer) below 200 knots above 25,000 feet or 250 knots above 45,000 feet.

F-34 may not contain corrosion inhibitor and F-35, JET A-1 and JET B may not contain icing or corrosion inhibitors. Restrict operation without icing inhibitor to one flight. Restrict operation without corrosion inhibitor to 10 consecutive hours.

HOT REFUELING

Stop short of the refueling area for tanks/stores safety check. If suspected hot brake or other unsafe condition exists, do not enter refueling area. Follow ground crew directions into the refueling area, and establish communications with the ground crew. If you suspect a malfunction stop refueling. Do not transmit on UHF except in an emergency. After refueling complete and when cleared by ground crew, taxi clear of the area. Do not use high power in congested areas.

Before entering refueling area -

1. After landing checklist - COMPLETE
2. Avionics - OFF (CC, AAI, ILS/TACAN, VSD, HUD, TEWS, RADAR)
3. Left throttle - OFF
4. Left engine master switch - CYCLE (before TO 1F-15-572)
5. Canopy - CLOSED
   Hot refueling with the canopy closed provides maximum protection in the event of a fire. Do not disconnect personal leads.
6. Fuel quantity - NOTE

During refueling -

7. Keep hands visible to refueling supervisor.
   Be prepared to shut down engine and evacuate aircraft or taxi clear of area as directed by ground crew if an emergency occurs.

After refueling -

8. Fuel quantity indicator - CHECK AND NOTE TOTAL QUANTITY

APPENDIX D

ANALYSIS, EVALUATION AND PRESENTATION OF TEST RESULTS

[redacted]

TABLE OF CONTENTS

INTRODUCTION

The final report on the fuel subsystem evaluation will give a brief description of the fuel system and draw attention to leading particulars and to the basic logic of its operation. For each test the aircraft model, designation and serial number will be given. The general approach will be to describe each group of tests in turn, briefly state the relevant evaluation criteria and state whether these are met. These criteria include both specification requirements and the general overriding requirement for operational suitability. If the fuel subsystem fails to meet a specification requirement it may still be considered operationally acceptable; Further it may meet specific requirements and still be considered operationally unsuitable.

When the criteria are not met enough detail must provided to effectively define the short fall in each case, tabular summaries will be given. Where appropriate, as in dynamic conditions in general, time histories will be presented with attention drawn to the important parameters.

For ease of reference objectives, pertinent paramenters, criteria and report presentation recommendations are summarized below for each test.

GROUND TESTS

Quantity System Calibration:

Objectives.

1. To determine usable fuel quantity.

2. To correlate usable fuel in the aircraft with indicated fuel quantity.

3. If center of gravity indication is provided, to compute actual versus indicated center gravity.

4. Specific objectives requested by the Program Office.

Key Parameters. Actual and indicated fuel in each tank, actual and indicated total fuel, actual and indicated fuel center of gravity if relevant; usable fuel, fuel density.

Criteria. Accuracy, and clarity, of fuel quantity presentation. Comments on behavior of the quantity system presentation under dynamic flight conditions should be included. Accuracy of low and "bingo" warnings.

Presentation. Data will be presented in narrative form supported by tabular and graphic data.

Narrative This will include overall results, conclusions, qualifying remarks, etc.

Tabular Data This will include the following:

1. Identifying information such as date, aircraft serial number, test point number, tank being filled/emptied, etc.

2. Aircraft weight.

3. Aircraft deck angle

4. Gallons of fuel removed or added since last weighing.

5. Temperature of fuel

6. Density of fuel (or specific weight)

7. Individual fuel quantity gauge readings and totalizer readings.

8. Operation of low level and " bingo" fuel warnings.

Graphic Data This will consist of plots of actual fuel weight (corrected for temperature/density) versus indicated fuel weight and indicator error versus actual fuel weight (with production tolerance bands shown). The volume of fuel at each tank cut-off will be shown.

Ground Refueling/Defueling Evaluation:

Objectives. These are:

1. To determine maximum ground refueling and defueling rates for basic airplane and airplane with external tanks.

2. To evaluate ground refueling/defueling procedures and checklists.

3. Specific objectives requested by the Program Office.

Key parameters. These are refueling rate in gravity and pressure refueling, defueling rate, practicality and problem areas.

Criteria. These are refueling rate and time to refuel, practicality and problem areas such as poor access, fuel foaming in gravity refueling, leakage, excessive manifold pressure, venting and any other safety items. Also ease, practicality and rate of defueling and safety/problem areas including ease and safety of defueling after a wheelsup landing. If hot turnaround is required criteria include speed, and special safety procedures required.

Presentation. Data will be presented in narrative form supported by tabular and graphic data.

Narrative This will include overall results, conclusions, qualifying remarks, etc.

Tabular Data This will include the following:

1. Identifying information such as date, aircraft, serial number, refuel/defuel method.

2. Begin and end fuel quantity

3. Elapsed time

4. Average or significant pressures

5. Remarks

Graphic Data This will include the following:

1. Fuel flow/fuel pressure relationships

2. Time history plots of surge pressures at tank shut-off.

3. Still photographs

Accessibility and Maintainability Requirements:

Accessibility and maintainability evaluation involves the Human Factors and the Reliability and Maintainability Branch within Flight Test Engineering and the Technical Order Verification Management Division of Maintenance and Supply. Usually the fuel subsystem flight test engineer will not take the lead role in these tests, but he should make himself, aware of what is being done and include appropriate data and comment in his report.

Objectives. These are:

1. To verify operational suitability

2. To verify compliance with the general requirements of MIL-F-038363.

3. To verify compliance with the appropriate end item specification.

4. Specific objectives requested by the Program Office.

Key Parameters. Accessibility and time required to perform manual servicing and maintenance, particularly items summarized in Table 6 (Page 65)

Criteria. These are:

1. Accessibility

2. Maintainability under operational condition with standard tools.

3. Criteria summarized in Table 6.

Presentation. This will include an overall assessment including favorable comment when applicable. In cases where the aircraft does not meet requirements sufficient detail must be given to clearly define the problem.

Narrative An overall assessment will be given, supported by sufficient narrative description to clearly define problems. Temporary and permanent solutions will be suggested when appropriate.

Tabular Data This will be used as appropriate to summarize results in readily understandable form. These data may be available from Reliability and Maintainability or from Technical Order Verifications.

Graphical Good photographic records are a most effective presentation tool and are essential.

Ground Fuel Transfer Evaluation:

These are:

1. To evaluate the normal fuel management system (if the fuel management system is automatic it may have been necessary to perform these tests, with engines running, along with the tests with boost pumps failed. These are discussed in the next group).

2. To evaluate fuel management procedures and check lists presented in the Flight Manual.

3. To evaluate backup/emergency fuel management procedures while on the ground.

4. To determine fuel transfer rates.

5. Specific objectives requested by the Program Office.

Key Parameters. Rate of transfer, center of gravity.

Criteria. Ease of accomplishment, impact on crew workload, logical sequence, safety and potential problem areas. Adequate control of center of gravity using fuel management proceduces and check lists presented in the Flight Manual.

Presentation. Data will be presented along with evaluations of in flight fuel management and data from inflight fuel transfer tests.

Narrative An overall assessment of fuel management procedures will be presented, with favorable comment as appropriate. Problem areas should be clearly defined and any temporary or permanent solutions suggested when appropriate. This assessment will cover both normal sequencing procedures and procedures used to correct imbalance.

Tabular Data Conditions tested, transfer times and other appropriate data will be presented in tabular form.

The tabular data will include the following:

1. Identifying information such as date, aircraft, serial number, test sequence number, etc.

2. Contributing tank

3. Receiving tank

4. Initial and final quantity readings

5. Center of gravity before and after transfer

6. Elapsed time

7. Remarks

Graphical Graphical presentation will be used as appropriate. Photographic documentation of problem areas is essential. Curves will be presented of center of gravity versus fuel remaining for systems using automatic sequencing, with center of gravity limits indicated if appropriate.

Ground Evaluation of Operation with Failed Boost Pumps:

Objectives. These are:

1. To perform a preliminary evaluation of fuel feed with boost pumps failed, as a precaution before proceeding to flight test.

2. To perform a preliminary evaluation of fuel sequencing, when this is automatic and cannot be tested without running the engines.

3. Any specific objectives requested by the Program Office.

Key Parameters. Engine fuel flows and engine fuel inlet pressure and, if fuel management is being evaluated, quantities in individual tanks and airplane center of gravity versus fuel used

Criteria. These are:

1. Absence of fluctuations

2. Engine fuel inlet pressure at least 5 psi above the fuel vapor pressure (Table 8, Page 73).

3. If automatic sequencing is being evaluated, control of center of gravity within prescribed limits and emptying droppable tanks first.

Presentation. Results will be presented along with results from subsequent flight tests in narrative form supported by tables and time histories.

Narrative The narrative description will briefly describe the tests performed and state when the results are satisfactory. If anomalies are encountered these will be described in sufficient detail to effectively define the problem.

Tabular Data Tests performed, test conditions and data will be summarized with appropriate comments.

Graphical Data Representative time histories will be presented which will include engine fuel flows and engine inlet pressures. If automatic sequencing is being evaluated, graphs will be presented of individual tank quantities and airplane center of gravity versus fuel quantities with center of gravity constraints indicated.

Ground Evaluation for Aerial Refueling:

The ground tests are to ensure that the aerial refueling system is acceptable to proceed to flight test. If results are satisfactory they will probably not be included in the final report, but adequate documentation, including photographic records, must be maintained.

Objectives. Specific objectives are to:

1. To perform fit and functional tests of the aerial refueling system and ensure receiver/tanker compatability prior to flight test

2. To determine fuel flow rate and pressures during fuel transfer

3. To determine surge pressures when the tanker fuel pumps are turned on, at shut-off of individual tanks (if applicable) and at fuel shut-off when the receiver is full.

4. To evaluate lighting for night refueling.

5. Specific objectives requested by the System Program Office.

Criteria. These include:

1. All components function satisfactorily

2. Tanker/receiver compatible

3. Surge pressure within limits

4. No leaks

5. Lighting for night refueling satisfactory

Presentation. Results of ground test, if satisfactory, will probably not be included in the final report but must be documented for internal record. Anomalies will be reported.

Narrative The narrative will summarize the tests performed and provide adequate description of anomalies.

Tabular Data Tabular summaries will be kept on the tests performed, test conditions, results and comments.

Graphical Time histories will be kept on the following:

1. Tanker fuel flow

2. Tanker fuel delivery pressure

3. Tanker fuel temperature

4. Total fuel transferred

5. Receiver manifold pressure

6. Individual tank contents

7. Number of tanker pumps operating

8. Surge pressure at shut-off and when receiver is filled to capacity.

9. Still photographs and motion picture records will be retained.

FLIGHT TESTS OTHER THAN AERIAL REFUELING

Functioning in Climbs, Dives and Maneuvers:

This is a very important part of fuel system flight testing which must uncover any potentially dangerous operating conditions within the flight envelopes in nominal and degraded fuel system operating modes.

Objectives. These are:

1. To demonstrate proper feed and transfer in climbs, rapid descents and all permissible stressing maneuvers.

2. To demonstrate proper pressurization and venting.

3. To demonstrate proper functions of explosion suppression subsystem, if of inert gas type.

4. Any specific objectives requested by the Program Office.

Key Parameters. These are engine inlet pressures, boost and transfer pump pressures, differential pressures across fuel tank walls and vent pressures.

Criteria. These are:

1. Satisfactory fuel feed to engines in all permissible maneuvers.

2. Ability to complete mission after a single failure.

3. Differentral pressures within design limits.

4. Ability to recover aircraft after a double failure.

5. Immediate attention of crew never required.

6. With inert gas type explosion suppression, the oxygen content in the inerted space not to exceed 10 percent.

Presentation. Data will be presented in narrative form supported by tabular and graphical data.

Narrative The narrative will summarize overall results, conclusions and any necessary qualifying remarks or explanation. Satisfactory operation will be specifically reported. Anomalies will be reported in sufficient detail to clearly define the problem.

Tabular Data Test conditions will be summarized in tables which will include the following:

1. Identifying information such as data, flight number, aircraft serial number, etc.

2. Begin and end altitude

3. Engine power settings

4. Airspeed

5. Flight condition, i.e, climb turn, normal load facter (n_z) sideslip, climb rate, etc.

6. Elapsed time

7. Remarks

Graphical Time histories will be presented for each test with the pertinent parameters identified (Table 9B).

Functioning and Fuel Management in Steady Level Flight:

These tests evaluate the functioning of the fuel system in long range cruise in the nominal operating mode and with various types and degrees of degradation by component failure.

Objectives. These are:

1. To demonstrate satisfactory feed, transfer and center of gravity control in nominal operation and with various levels of component failure.

2. To demonstrate low fuel warning.

3. Specific objectives requested by the Program Office.

Key Parameters. These will include:

1. Flight condition (airspeed, altitude, Mach no.)

2. Engine settings

3. Engine fuel flow

4. Engine fuel inlet pressures

5. Fuel temperatures

6. Transfer rates and sequences

7. Quantities in tanks

8. Center of gravity position

Criteria. These include:

1. Satisfactory automatic sequencing and center of gravity control on aircraft normally operated by a single pilot.

2. Crew work load, on aircraft not normally operated by a single pilot, and clarity of procedures.

3. Immediate attention of crew never required.

4. Simplicity and clarity of procedures in degraded modes.

5. Correct operation of low level and "bingo" (pilot set) warnings.

Presentation. Results will be presented in narrative form supported by tabular and graphic data.

Narrative The narrative will summarize overall results, conclusions and any necessary remarks and explanations. Satisfactory operation will be specifically reported. Anomalies will be reported in sufficient detail to effectively define the problem.

Tabular Data Tabular summaries will be presented of the conditions tested, which will include nominal and degraded operating modes, with comments on operation as appropriate. Conditions under which anomalies occurred will be defined in tabular form listing all pertinent conditions. These will vary between cases but will at least included the key parameters listed above.

Graphical Time histories will be presented of the key parameters in all anomalous cases.

Fuel Transfer Tests:

Tests will also be made specifically to evaluate correction of lateral or longitudinal center of gravity by fuel transfer.

<u>Objectives</u>. These are:

1. To determine inflight fuel transfer rates.

2. To evaluate fuel management procedures and checklists presented in the Flight Manual.

3. Specific objectives requested by the Program Office.

<u>Key Parameters</u>. There are:

1. Identifying information such as date, flight number, aircraft serial number, test sequence number, etc.

2. Contributing tank

3. Receiving tank

4. Begin and end fuel quantities

5. Elapsed time

6. Altitude

7. Airspeed

8. Flight conditions, i.e., turn, climb, normal load facter (n_z), sideslip etc.

9. Crew workload

<u>Criteria</u>. These are:

1. Ease of accomplishment of transfer.

2. Impact on crew workload

3. Practicability, logical sequence of check list items potential problem areas and safety.

<u>Presentation</u>. Presentation will be in the form of a narrative supported by tabular and graphic data as appropriate. Both flight tests and preliminary ground tests will be covered.

<u>Narrative</u> The tests performed will be briefly summarised and overall conclusiions stated. Problem areas will be described in sufficient detail to enable the reader to understand the problem.

<u>Tabular Data</u> These will summarize the conditions tested, including the key parameters listed above, with comments.

Graphical Time histories will be included as appropriate. Photographic documentation of problem areas should be provided if needed for clear presentation of procedural difficulties.

Fuel Jettison Evaluation:

Objectives. These are:

1. To evaluate the capability and safety of fuel jettison.

2. To determine fuel jettison rates.

3. To evaluate the checklists presentd in the Flight Manual.

4. Specific objectives requested by the program office.

Key parameters. These are:

1. Altitude or altitude range

2. Airspeed or airspeed range

3. Begin and end fuel quantity in each tank being dumped.

4. Elapsed time

5. Flight conditions, i.e., normal load factor n_z, sideslip, climb, etc.

6. Any impingement of fuel on or entry of fumes into any part of the aircraft.

7. Any safety problems

Criteria. These are:

1. Ease and safety of jettison procedure

2. Time required

Presentation. Data will be presented in narrative form supported by tabular and graphic data.

Narrative This will summarize overall results, conclusions and necessary qualifying remarks. Optimum jettison conditions and sensitivity to these conditions will be briefly discussed.

Tabular Data Tabular summaries will be presented of the test conducted, including the key parameters above, remarks, and flight identification (date, flight number, aircraft etc.)

Functioning with Cross Feed and During Transients:

Objectives. These are:

1. To demonstrate that any/all engines can be fed satisfactorily from any tank(s).

2. To demonstrate that fuel flow to one engine can be varied without affecting fuel flow to other engine(s).

3. To demonstrate satisfactory transient response to changes in engine setting, boost pump operation and other pertinent operating conditions.

4. Any specific objectives requested by the Program Office.

Key Parameters. These are:

1. Engine fuel inlet pressures

2. Fuel flows

3. Quantities in tanks

4. Engine settings

Criteria. These are:

1. That all/any engines can be fed from any feed tank throughout the range of required fuel flow.

2. That the fuel flow to any engine can be changed without affecting the fuel flow to other engine(s).

3. That no adverse transients result from changes in engine setting, boost or transfer pump operation or cross feed arrangement.

Presentation. Data will be presented in narrative form supported by tabular data and time histories.

Narrative This will summarize overall results including areas of satisfactory operation, conclusions and necessary qualifying remarks. Anomalies will be reported in sufficient detail to effectively define the problem.

Tabular Data Tabular summaries will be presented of the tests conducted which will include the key parameters and appropriate comments on the results.

Graphical Time histories of key parameters will by presented for all transient response tests.

AERIAL REFUELING

As has already been stated, aerial refueling tests involve the compatibility interface between two aircraft, receiver and tanker, as well as the functional adequacy of the aerial refueling system on the receiver. Because of this, testing, analysis and evaluation require flexibility and alertness on the part of the flight test engineer and are less suitable than many other aspects of fuel system testing to a fixed, cookbook approach.

Aerial refueling subsystem evaluation is similar in most respects for boom/receptacle and probe/drogue techniques. For the sake of conciseness and clarity the discussion below primarily addresses the boom/receptacle technique, with variations associated with the probe/drogue technique pointed out when necessary.

The following areas will now be discussed:

1. Flight envelope evaluation

2. Contact and disconnect envelope evaluation

3. Fuel transfer rate and pressure surge

4. Reverse refueling

5. Emergency/backup mode evaluation

6. Night operation

Flight Envelope Evaluation:

Objective. The objective of this phase is to determine the best airspeed/altitude ranges over which the receivers and the tanker are compatible over adequate ranges of gross weights.

Key Parameters. These are:

1. Receiver and tanker gross weights and centers of gravity.

2. Airspeed

3. Altitude

4. Turbulence

5. Relative positions

6. Engine settings

7. Flap settings/speed brake settings

8. Any handling problems

Criteria. These are:

1. Ease of position keeping, handling qualities.

2. Weight, altitude and speed ranges over which the tanker and receiver aircraft are compatible sufficient for adequate fuel transfer.

Presentation. This will consist of a narrative supported by tabular and graphical data (including photographic).

Narrative A narrative discussion will be presented of the speed/altitude/weight and relative position compatibility envelopes, and of the associatead handling qualities of the two aircraft. Comments will be made on the factors limiting the range of compatibility and on any significant problem areas. In tests using a Boom Drogue Adapter the limits on boom elevation angle will be discussed.

Tabular Data Tabular summaries will be presented of the key parameters for all conditions tested with appropriate remarks.

Graphical Plots will be presented of the altitude, airspeed, boom angle and boom extension envelopes. Photographs will be included as appropriate. (Photo coverage under the next tests (contact and disconnect) may be sufficient.)

Contact and Disconnect Envelope Evaluation:

Objective. The objective of this test is to estabilish the boom azimuth, elevation and extension envelopes (KC-135) or roll, elevation and extension envelopes (KC-10) over which contacts and disconnects can be performed without interference or binding between boom nozzle and receptacle or other problems. For probe/drogue refueling with the KC-130 or KC-10 the parameter is the position of the receiver, since there is no boom.

Key Parameters. These are:

1. Flight conditions

2. Boom elevation (if applicable)

3. Boom azimuth (KC-135) or roll angle (KC-10) (if applicable)

4. Boom extension (if applicable)

5. Receiver position (probe/drogue) at inner and outer drogue limits.

6. Boom/probe loads at contact or disconnect

7. Drogue extension (probe/drogue)

8. Turbulence (normally qualitative, but supported by quantitative measure if available).

Criteria. These are:

1. Boom/probe loads at disconnect

2. Clean disconnect

3. Envelope limits

Presentation. A summary narrative will be given, supported by tabular and graphical data including photographs.

Narrative An overall narrative summary will be presented giving areas of satisfactory operation and discussing the criteria by which the disconnect envelopes were established. Problem areas such as binding of the nozzle will be adequately defined.

Tabular Data Tabular summaries will be presented for all the tests giving test identification data, the values of the control parameters and comments.

Graphical Plots will be provided of the disconnect envelope. Photographs will be included as appropriate.

Fuel Transfer Rate and Pressure Surge Evaluation:

Objectives. This is to determine the maximum transfer flow rates which can be achieved without exceeding the design limits on steady state and surge pressures and the associated combination of receiver tanks and flow rates (number of operating tanker pumps).

Key Parameters. These are:

1. Surge pressures

2. Steady pressures

3. Fuel flow rate

4. Receiving tanks

5. Number of tanker pumps operating

6. In the case of probe/drogue refueling, time to completely fuel the receiver from minimum fuel to full.

7. In the case of the KC-130, surge pressure due to disconnect of a second receiver aircraft on the opposite drogue.

8. Total fuel transferred.

Criteria. The surge and steady state pressures must be within design limits when the particular combination of receiver tanks and flow rates is used.

Presentation. Presentation will consist of narrative, supported by tabular and graphical data (including photographic).

Narrative A narrative summary will be presented of overall results and conclusions, with qualifying comments as necessary. Anomalies will be described in sufficient detail to effectively define the problem.

Tabular Data Tabular data will include the following:

1. Identifying data such as date, flight number, aircraft serial number, day or night, test sequence number, wet or dry contact, type disconnect, etc.

2. Boom position

3. Airspeed

4. Altitude

5. Fuel flowrate

6. Steady state fuel pressure

7. Number and identification of receiver tanks

8. Surge pressure

9. No. of tanker pumps used

10. Total fuel transferred

11. Flight conditions

12. Remarks

Graphical The graphic data will present fuel flow versus number of accepting tanks and fuel manifold pressure versus fuel flow. Photographs will be included as appropriate.

Reverse Refueling:

Objective. The objective of this task is to verify the feasibility of reverse refueling from a large receiver aircraft to the tanker and to determine the relationship between flow rate and the number of supplying tanks/pumps per tank being used to reverse refuel the tanker.

Key Parameters. These are:

1. Flow rate

2. Number of supplying tanks/pumps

3. Tanks being reverse refueled

4. Manifold pressures

5. Total fuel transferred

Criteria. The primary criteria are flow rate and the required numbers of supplying tanks and pumps per tank.

Presentation. Results will be presented in the form of narrative supported by tabular and graphical data with photographs as appropriate.

Narrative The narrative will summarize overall results, primarily feasibility and capability, with comments and qualifying remarks as necessary.

Tabular Data Tabular data will include flight/test identification, the above key parameters and comments.

Graphical Curves such as plots of flow rate versus number of pumps should be presented if the results are compatible with this format, with photographs as appropriate.

Emergency/Backup Mode Evaluation:

Objective. The objective of this task is to evaluate functioning in emergency/backup modes such as:

1. Manual opening of refueling door

2. Emergency boom latching

3. Stiff boom refueling (pressure refueling)

4. Tension disconnects

5. Independent disconnect (KC-10).

Key parameters.

Manual opening of refueling door Simple verification unless problems occur, then the nature and flight circumstances of the problems.

Emergency boom latching As above

Stiff boom refueling Key parameters are

1. Flow rate

2. Fuel pressure

3. Flow leakage

4. Flight conditions

Tension disconnects Key parameters are

1. Boom loads at tension disconnect and independent disconnect.

2. Boom position

3. Flight conditions

Presentation. Reporting will consist of a narrative summary of results supported as necessary by tabular and graphical (including photographic) data.

Narrative Narrative reporting of objectives 1 and 2 will simply report verification unless problems are encountered, in which case the problems must be discussed in sufficient detail to effectively define their nature. Narrative reporting of objectives 3, 4 and 5 will summarise results with appropriate comments and qualifications.

Tabular Data If anomalies occur with objectives 1 and 2 sufficient tabular data will be presented to effectively summarize the problems and the conditions under which they occur. For objectives 3 and 4 tabular data will be presented which will include.

1. Flight and test identification

2. Flight conditions

3. Fuel flow rate (objective 3)

4. Fuel leakage (objective 3)

5. Boom position

6. Boom/loads at disconnect (objective 4)

Graphical Photographs must be provided as appropriate to illustrate problem areas.

Night Operation:

Objective. The objective of this test is to evaluate the suitability of the lighting for night operation.

Criteria and Key Parameters. These are:

1. Similarity of approach, hookup, disconnect, and backaway procedures to daylight operations.

2. Effectiveness placement, brightness/dimness and aiming of receptacle and formation lights.

3. Availability and usefulness of visual references, vertigo tendencies, etc.

4. Distractive light sources within the receiver cockpit such as instruments, radar scopes, etc.

5. Effectiveness of director lights

Presentation. A narrative presentation will be used summarizing the comments made by a cross section of crews in both aircraft on the above subject. Photographic illustrations should be included if appropriate.

ALL-WEATHER TESTING

All weather testing of the fuel system is integrated into all weather testing of the total aircraft and support system to evaluate operational suitability over the full required range of environmental conditions. For detail of facilities and procedures See Reference 3.

Objectives:

These are:

1. To verify that the fuel system operates without deficiencies over the full range of environmental conditions without attention from the crew.

2. To verify serviceability and maintainability over the full required range of environmental conditions.

3. Any specific objectives requested by the System Program Office.

Key Parameters:

These are the parameters identified in Table 9A and 9B (Page 72) for the individual tests discussed earlier plus any additional parameters necessary to define test conditions such as:

1. environmental parameters (test humidity, dew point, rain conditions)

2. duration of hot or cold soak.

3. fuel temperatures

Criteria:

These are for the individual tests discussed earlier plus:

1. functioning of seals etc

2. functioning of components such as refueling doors, latches, etc.

Presentation:

There may be two reports. An All-Weather testing report will address the All-Weather test program as a whole, describing the test setup and giving full details of the operational profiles flown or simulated. Results specific to the fuel system will, however, usually be reported in a fuel subsystem evaluation report. This report will summarize the test conditions covered and the types of operational profiles flown or simulated.

Narrative. A narrative summary will be given including a general statement of satisfactory operation of a component when appropriate. Problem areas will be reported in sufficient detail to clearly define the problems and the conditions under which they occur.

Tabular Data. Complete tabular summaries must be presented of the tests and test conditions with comments.

Graphical. Time histories and other graphical data will be presented as appropriate. Full photographic documentation is essential.

ALTERNATE FUEL TESTING

Objectives: These are:

1. To evaluate fuel subsystem operation on alternate fuels.

2. To identify differences in operating characteristics of the fuel system with alternate fuels as compared to operation on the primary fuel.

3. To check for leaks

4. Specific objectives requested by the System Program Office.

Key Parameters:

Key parameters are fuel transfer and cg control, fuel temperature, quantity system calibration.

Criteria:

The fuel system shall function satisfactorily over the full range of operational conditions using nominal procedures or reasonable special procedures.

Presentation:

Data appropriate to the specific test will be presented, as discussed above for tests with the baseline fuel under the appropriate headings. Fuel sample reports on the batches of alternate fuel used will be included (heat of combustion, density, viscosity, flash point).

Satisfactory operation will be summarized in clear statements that the function was satisfactorily performed. Problem areas will be reported in sufficient detail to clearly state the problem and the conditions under which it was encountered, with photographs as appropriate.